IRIS AperTO

UNIVERSITÀ DEGLI STUDI DI TORINO

AperTO - Archivio Istituzionale Open Access dell'Università di Torino

Metabolic exchanges and practices of regulation: The assemblage of environment and society in early social sciences

This is the author's manuscript

Original Citation:

Availability:

This version is available http://hdl.handle.net/2318/155888 since

Published version:

DOI:10.1016/j.ecoinf.2014.02.006

Terms of use:

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)

19 April 2024

Ecological Informatics xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Ecological Informatics

journal homepage: www.elsevier.com/locate/ecolinf

Metabolic exchanges and practices of regulation: The assemblage of environment and society in early social sciences

Dario Padovan *

Department of Culture, Politics and Society-University of Torino, Campus Luigi Einaudi, Lungo Dora Siena 100 A-10153, Torino, Italy

ARTICLE INFO

Article history:
Received 19 July 2013
Received in revised form 31 January 2014
Accepted 25 February 2014
Available online xxxx

Keywords:
Societal metabolism
Nature appropriation
Labor
Social practices
Teleology
Mechanism

ABSTRACT

In this paper I discuss the way in which early sociology addressed the metabolic relationships between society and nature. Father founders of social science such as Comte, Spencer, Marx, Schaeffle, Lilienfeld, Giddings, Ward, Kidd, Geddes and some others shared a physiological vision of metabolism and all were concerned on the problem of social regulation of metabolism. On closer examination, early social sciences had realized that social and natural worlds are deeply interconnected even though they were trapped in the dilemma between mechanism and finalism. A metabolic perspective allows us to understand where the organic interchange between nature and society has problems endangering social reproduction. Yet, metabolism is not only a matter of physical sciences but also of social ones for it is ruled and driven by social agents. Given the set of practices, knowledge, and sociotechnical regimes that enable the metabolism, it is notable the almost entirely absence of a sociology of metabolic exchanges, of the manner in which social systems (towns, firms, households) consume "environment", i.e. matter, energy, and bio-capacity. The paper suggests that social scientists should investigate in the field of societal metabolic processes in an interdisciplinary perspective for exploring metabolic activators such as organized labor, consumption, and practice regimes as was suggested by early sociologists.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Society draws matter, energy and services from nature for the production of goods and services necessary to ensure the bio-psycho-social continuity of its members and of those infrastructures that continually recreate the possibility of its own existence. Problems posed by environmental crises deeply affect the reproduction of global social systems and thus have become an object of social sciences research. However, contemporary sociology has rarely engaged with the reproduction processes that I call social metabolism.

In previous articles, I have dealt with analogies that sociologists of the nineteenth and early twentieth century employed to explain the links between society and nature (Padovan, 2008; 2003). In this paper, I try to show that early sociology developed material approaches that incorporated nature into foundational sociological models. Among early sociologists, the suggestion of social metabolism was widely adopted. It was used to describe mechanisms of action, reaction and adaptation that occur in the context of relations of exchange and transformation between society and nature. This vision could now be called coevolution. However, it also had other meanings. For some authors, coevolution was a matter of morphology and analogy that paid attention to a society's internal organization and its embedding in natural evolution; for others, it was a matter of physiology, a way of describing the functional exchange of energy and matter between society and the environment and how to overcome the resistance of matter, thereby allowing social achievements; for still others, social metabolism was a problem of the organization, transformational activities, and technical regimes of both labor and of a broader social regulation.

At that time, elements of an interesting materialist ontology emerged, most likely derived from the influence of antimetaphysical positivism, as in the case of Comte and Spencer or, among natural scientists, Moleschott and Haeckel. In some sense, they indirectly denied the sociocentric determinism, based on the Cartesian society/nature detachment, which characterized the social sciences of the twentieth century. At that time, there was not yet a functional distinction between the status of actor and *acted-upon* and foot and *footprint* that was as clear as conventional metaphors used today (Moore, 2011). As argued by Jason Moore (2009), the social makes history, but not within biophysical relations and determinations of its own choosing. Society is as much biophysically constructed as nature is socially constituted, even as these constructions and constitutions reveal distinctive modes of operation. In other words, early sociology provides some insights into the reciprocity and circularity of social and material changes, the role of living organisms and "matter" in social sciences and the closing of the separation between the cultural and the material (Reckwitz, 2002).

The prevailing early sociological models, with minor differences, insisted on the metabolic coevolution of nature and society, relying primarily on their formal and functional similarities. However, Comte,

* Corresponding author. Tel.: +39 0116702606; fax: +39 0116702612.
E-mail address: dario.padovan@unito.it.

http://dx.doi.org/10.1016/j.ecoinf.2014.02.006
1574-9541/© 2014 Elsevier B.V. All rights reserved.

Please cite this article as: Padovan, D., Metabolic exchanges and practices of regulation: The assemblage of environment and society in early social sciences, Ecological Informatics (2014), http://dx.doi.org/10.1016/j.ecoinf.2014.02.006

ARTICLE IN PRESS

Spencer, Schaeffle, and Haeckel, just to name a few, went beyond the old idea that society is an organism. They considered this similitude as proof of the coevolution of society and nature. The constant exchange of analogies, metaphors, models and experimental data among disciplines such as biology, astronomy, physics, economics, physiology, and sociology provided an opportunity to investigate living and nonliving organisms (from the smallest invertebrate to human societies) in terms of metabolic systems that coevolve with their environment. Comte developed a societal embryology, Spencer an epigenetic social model, Haeckel a biogenetic fundamental law.

The metabolism approach provides an interesting reading of the relations between exteriority and heterogeneity that stem from the society/nature complex. In addition, this approach highlights the need to think of society and nature as reciprocally embedded. Finally, it seems possible to overcome the classical dualism between idealism and materialism, culture and matter, and language and object, reincorporating the material (natural) into the social (cultural). In a few words, metabolic approaches announce that the "material" coexists and coevolves with the "cultural". This means that, as suggested by Bronislaw Szerszynski, the "metabolism of the human–technology ensemble needs a biosemiotic analysis" simply because "each organism inhabits its own semiotic environment, constituted by the 'carriers of significance' to which its senses are attuned" (Szerszynski, 2010: 13).

A new metabolic perspective has been developed during the last thirty years, primarily by the Harvard school of industrial metabolism, the IFF Wien school of societal metabolism, and the Oregon school of metabolic rift. These schools of thought encouraged different disciplines—such as physics, ecology, biology, geography, economics, sociology, anthropology, and organizational studies—to reciprocally collaborate. In the beginning, the metabolic perspective was used as a paradigm to describe the exchange of matter between a city and its environment (Wolman, 1965) or among industrial operations in a manner that was analogous to the description of material and energy balances in natural ecological systems. However, the current development of some metabolic approaches is lacking in some aspects. For instance, they are unable to establish a link to the actors responsible for activating and changing metabolic processes, and therefore, it is not clear which social actors should contribute to a strategy of balancing metabolism. In this paper, I attempt to outline a sociological history of metabolism that is a little bit different from that outlined by Fischer-Kowalski (1998) and Fischer-Kowalski and Hüttler (1999) and that is useful, I hope, for fostering ideas to open the chapter on societal metabolism ruling agents.

In the first section, I give a more accurate account of the metabolic basis of early sociological thought, stressing agreements and contradictions. In the second section, I give an account of ontological and epistemological problems connected with the physicism/vitalism and society/nature dualisms, which still exist, albeit in different forms. In the third section, I attempt to show that there already exists a sound basis for a sociology with a strong foundation in society/nature metabolism. In the fourth and fifth sections, I attempt to outline a connection between social metabolism, labor and social practices. In the sixth section, I engage with a critical analysis of the socioeconomic regulation of metabolic mechanisms that transforms them into colonial or imperialistic accumulative regimes.

2. The metabolic approach at the dawn of sociology

Nineteenth-century social scientists believed that society was not only a sui generis entity but also a living organism that based its reproduction on matter and labor. Comte, Spencer, and Giddings were interested in the physiology and functions of organisms; for Novicow, Lilienfeld, Espinas, and Kidd, the morphology of social and biological organisms and their analogies were most important; Marx, Schaeffle and Kropotkin focused on the societal organization of labor and consumption as conditions of metabolism. The metabolic hypothesis increased the need to study peculiar phenomena of the nature/society complex, such as consumption, circulation, exchange, processing, storage, dissipation, growth, structuration, differentiation, evolution, colonization, and so on. The metabolic hypothesis also contains a mutualist perspective because every living organism exchanges energy and matter with its environment so that both can reproduce. Thus, it is possible to call this metabolic approach social "physiology", as suggested by Kropotkin (Padovan, 1999).

To early sociologists, society appeared as a living body, the highest manifestation of the process of organic evolution caused by an unceasing relationship between the organism and its environment. Auguste Comte believed that the study of man must necessarily pass through the study of the external conditions in which he reproduces himself, simultaneously as a biological species and as a society. Depending on the direction of scientific knowledge, from the man to the world that surrounds him or vice versa, different philosophies, one teleological (sometimes mixed with metaphysics) and the other positive, developed. The prevalence of an anthropocentric view meant that phenomena were interpreted on the basis of extranatural willingness, not natural laws. According to Comte, the anthropocentric view reconciled the two perspectives, subordinating the conception of man to that of the external and material world (Comte, 1838: 269–271). How did Comte define life? He considered it to be the condition of the existence of organized beings or their "double interior motion, general and continuous, of composition and decomposition, which in fact constitutes its true universal nature" (Comte, 1838: 295). This definition, as Comte himself admitted, can only be coextensive with the condition of organism/environment inseparability; it can only suggest the joined double existence of an organization ready to allow continuous internal renewal and an environment capable of absorbing and emitting. In short, the living are those organisms equipped with a metabolic process.

Each individual organism cannot have a life independent of the environment that surrounds it. "Life" is not the property of a particular type of substance, as the metaphysicists believed. Rather, it is the combination or the harmonious cooperation of two inseparable elements, the organism and the environment or milieu (ibid: 289). The living being and its environment are therefore in a state of mutual cooperation and dependence. Additionally, the more complex the organism is, the more complex the environment that surrounds it must be. This principle is particularly true for human societies, where things and events are generally remote in time and space. Man cannot live except under the most complex set of favorable external conditions, both weather and chemical–physical in nature (ibid: 292). In short, there is no evidence to support the independence of living bodies from their environmental conditions. Of course, organisms are able not only to adapt passively to the environment but also to interact freely with it, thus modifying it. From this ability to transform the environment derives the power of the organism to withstand high levels of variability in environmental conditions, properties that today we would call "systemic resilience."

Only a deeply disturbed environment could threaten the living, simply because the mode of existence of living bodies is clearly characterized by a strong dependence on external influences, both for the variety of different actions that are required and for the intensity of each of those actions. Comte therefore rejected both the idea of an organism's total independence from the environment and the concept of a body that is passively deformable under the pressure of the surrounding environment, which denies any individual adjustment by the living. In these words, we can see that Comte positioned himself between the two poles of vitalism and mechanism.

In a sociological sense, Comte was very skilled at extending the constitutive relation between organism and environment. Once recognized as necessary for the manifestation of various living phenomena, such as the corelationship and mutual action between organism and environment, or in other words metabolism, it was necessary to define the series of acts or actions that constituted them. According to Comte, it

Please cite this article as: Padovan, D., Metabolic exchanges and practices of regulation: The assemblage of environment and society in early social sciences, Ecological Informatics (2014), http://dx.doi.org/10.1016/j.ecoinf.2014.02.006

ARTICLE IN PRESS

was necessary to constantly bind, in both a general and a particular manner, the organism–environment indissoluble couple with the idea of function. Function corresponds to a series of acts or activities by virtue of which not only do the environment's actions change organisms but changes in the organisms themselves transform their environment. This reciprocity of action, similar to physical and mechanical action and reaction complexes, is essentially the function, i.e., the twofold outcome of the tension between organism and environment (Comte, 1838: 301–302). Ingenious intuition, which presupposes not only that a number of interrelated practices between system and environment appear but also that any change inside the system caused by such actions sets in motion further changes in the environment.

Finally Comte noticed his own wavering between a hierarchical scientism and a stringent anthropocentrism. He believed that the necessary condition that rendered universal progress, both biological and social, possible was nothing less than the enslavement and control of inert matter by whole life, in light of an innate social subjectivity. Life had to reproduce and arise through an exhaustive struggle against inorganic matter, against nonliving nature. Here lies Comte's devotion to scientific progress that also constitutes an embryonic governmental program of societal metabolic processes.

René Worms added some interesting reflection on this issue. For him, as Comte had already stated, environment was an array of elements that nature provided to society, which then used those elements for its own purposes. Physical phenomena were embedded in social and biological phenomena (Worms, 1896). Material was the basis of social and physiological phenomena working as intermediating aspects between the social and the material. Worms distinguished nonhuman elements of society into two classes: those that were truly natural and formed the environment and those that drew their form from human labor (Worms, 1907: 18–19). Worms identified several elements that constituted the environment of the social system: the soil on which society placed its habitat; the subsoil, from which society took various materials and other organisms to use for food, indirectly contributing to human foodstuff; and aboveground, with its elements such as atmosphere, rain, solar energy, and the plants and animal organisms, essential for social life (Worms, 1907: 19–20). Worms noted that the action of these elements was significant to the point that it was impossible to believe in social life in the absence of the environment. The social role attributed to this long series of nonhuman elements was very clear. The idea that they could be replaced with synthetic inorganic products was very far away. Neither Worms nor Comte lacked the awareness that society changes its environment, but it is the way in which society manipulates, transforms, and uses the environment that indicates the type of society where we live and what type of individuals belong to it. The metabolic process in itself is a transforming factor, noted Worms, but the success or failure of cooperation between a social system and its environment depends on the quality of social organization and the regulation of metabolism itself (Worms, 1907: 29–30).

Although he was a strong supporter of extreme liberalism, the bio-psycho-sociological system developed by Herbert Spencer undoubtedly had a metabolic character. Spencer believed in a close correlation between plant and animal life, recognizable in the correlation between the amounts of energy expended by each animal species and the amount of energy emitted by plants during oxidation (Spencer, 1880: 182). This general law of energy transformation and equivalence concerned both vital and social forces. In fact, Spencer's main idea was that social forces were strictly correlated with physical forces, mediated by vital forces.

Everything that occurs in a society is due to organic or inorganic agencies, or a combination of the two; either from undirected physical forces, from those physical forces directed by men, or from the forces of the men themselves. According to Spencer, a clear demonstration of the correlation between living and social phenomena is provided by the influence of population on the features of society that it helped form. The larger the population, the larger and more diverse the set of social practices exhibited by the system. Similarly, social activity varies based on the size of the supply of organic and inorganic matter from the environment. Abundant natural resources obviously have a positive influence on the complex profile of society through increasing the organism's social activities and complexity (Spencer, 1880: 189–190).

According to Spencer, the efficiency and extent of social metabolism determines societal wealth, and where resources are not obtainable from already-colonized land, they are imported from other regions at the expense of other forces and energies. The indifference of the consumption of energy and materials to the place from which those resources are drawn was already clear, along with the fact that all societies have the never-ending supply of energy appropriated by living organisms: solar energy. The specific ability of human society is to be able to use and appropriate even the most subtle and difficult-to-find sources of energy, such as coal, wind or water, using tools and techniques invented by the human species. Societal prosperity can only depend on the prosperity of the life forces that surround it and which provide the elements necessary for its development. However, at the same time these same forces limit the movement of the social system's growth and expansion, the boundary beyond which resistance becomes stronger and stronger as well as more and more complex (Spencer, 1880: 240).

The Spencerian dilemma lies in the absence of a theory of the limit, or rather in adhering to the anthropocentric idea of continuous growth of the social organism at the expense of other species and other human societies. This is where the biosociological Spencerian evolutionism, distorting Darwin's assumptions, takes shape, fueling the idea of an incessant effort to move the boundaries between society and the environment in an effort to permanently colonize the natural and social environments.

Natural selection was initially conceived as the process of an organism's adjustment to its environment. At that time, it seemed that the same principle could be applied to the social phenomena of human life. From this perspective, according to Spencer, human society is considered to result from natural causes broad enough to include the cosmic process. As Lilienfeld suggested, social improvements occur only when the adjustment process is both incessant and dynamic. If the metabolic process stops or goes too fast, society jeopardizes its own reproduction. Human society, like any organism, adapts to ceaseless environmental variations. It harmonizes not only with natural environmental modifications such as climate, food and vegetation but also with the new conditions produced by psychosociological activity and economic actions. These activities create an artificial environment, different but still linked to the natural environment (Lilienfeld, 1896).

Society does not have its own laws that differ from natural ones, argued Giddings, and sociology must give an account of the origins, growth, and structuration of society from the point of view of the joint evolution of natural and social phenomena (Giddings, 1896). Sociologists such as Giddings naively believed that the laws of social evolution are the same laws that govern natural evolution. In fact, some processes and mechanisms, such as integration and differentiation, or the transition from disorganized homogeneity to organized heterogeneity, are formally and analogically found in both fields of life. The basic idea is that the adaptation of a society to its environment is harmonious, painless, and completely irenic, like the laws of nature. If there are changes, they aim to achieve equilibrium, as in the case of thermodynamic laws based on the universal tendency to balance energy between bodies. Thus, the ideas of social “static” and “dynamic” were considered complementary disciplines for the study of equilibrium and social change. Their final synthesis is found in the Spencerian “dynamic equilibrium”, i.e., the continuous processes of adaptation between system and environment to achieve a balance.

However, society does not act like nature. Society takes possession of nature through practices, processes, and mechanisms that emulate natural ones only initially, and then turn away permanently. Society converts and replaces the natural process of evolution in an artificial

Please cite this article as: Padovan, D., Metabolic exchanges and practices of regulation: The assemblage of environment and society in early social sciences, Ecological Informatics (2014), http://dx.doi.org/10.1016/j.ecoinf.2014.02.006

ARTICLE IN PRESS

process in which society decides its own destiny. The evolutionary process becomes teleologically progressive, and is ideally no longer physically guided by certain compelling "ideas-force" (Fouillée, 1890, 1905). Here, sociology discovers the need to combine two major perspectives: the objective related to the physical, and the subjective related to the social will. A true sociology, argued Giddings, must combine objective and subjective interpretations. The metabolic evolution of society necessarily leads to a distinction, which would mean replacing the primordial driving forces of physical nature, necessary for the establishment of society, with social forces. In the case of Giddings, it is the consciousness of species, a central phenomenon of social life, which allows the various stages of human evolution to remain connected.

In more analytical terms, species consciousness is formed by an association of individual minds that belong to human societies, as argued by Lester Ward (1884). Modes of association arising out of the combination of minds comprise a new environment for individuals, a medium that lies between the individual consciousness of species and the outer world of nature. Outlined in this passage is the primary interface between society and nature, a psychosocial system that remains dependent on outside nature, but imperceptibly and gradually emancipates itself from material needs, building a first distinction between inside and outside, between us and the other (Giddings, 1896: 25). In this way, social activities are able to create a "wonderful structure" of external relations that acts causally on the environment by modifying the surface of the earth. For the first time, the process of adaptation becomes unbalanced in favor of society, announcing the decoupling of society and nature.

In this first stage, relationships between society and nature were seen by sociologists as a slow but inescapable process by which society constitutes itself. However, soon society begins to emancipate itself from physical nature. The rise of political and economic institutions, along with technical and organizational configurations, made available the rise of social systems at the expenses of natural ones. Sociologists believed that from the same point of departure, evolution leads to a separation between nature and society. According to Spencer, industrial progress not only exhibits a compound acceleration resulting from an increase in operative forces but also exhibits further acceleration resulting from a decrease in resistance by natural and physical elements (Spencer, 1900: 327). The ability of a social system to maintain a functional balance with the environment is a matter either of organization and cooperation or of social consciousness and driving ideas.

3. Metabolism between mechanism and finalism

The affirmation of positivism and materialism during the 19th century led to a fracture in the natural and social sciences between vitalism or finalism and mechanism or physicalism. As set forth below, this fracture divided both natural and social scientists. According to, e.g., Haeckel, reproduction, adaptation and nourishment are biological functions of organisms that deny every teleological, spiritual and vitalist interpretation of organic life, although they are understandable in light of a mechanical and physicochemical conception (Haeckel, 1866, 1900). Comte's position existed between the two extremes of vitalism and materialism. Materialists exaggerated the subordination of biology to the simpler parts of natural philosophy, and went so far as to assign the study of life to the appendix of the general system of inorganic physics. Vitalists' consequent reaction resulted in the development of a metaphysical doctrine of physiology. The strength of their metaphysical dogma resided in its recognition of physiology as a distinct science, whereas the strength of physicochemical dogma resided in its principle of the dependence of organic on inorganic laws. He also believed that vitalism and materialism were connected to ideological and political movements—to reactionary and revolutionary movements, respectively (Comte, 1838: 648–649).

Recent concepts of metabolism seem closer to the mechanicist approach than to the teleological one. Whereas metabolism refers to a complex process of metabolic exchange, whereby an organism (or a cell) draws upon materials and energy from its environment and converts them, using various metabolic reactions, into the building blocks of proteins and other compounds necessary for growth (Fischer-Kowalski, 1998), here we are confronted by a nonteleological definition. Although it is said that metabolism refers to the internal processes of a living organism that needs energy-rich, low-entropy materials (food) both to provide for its own maintenance and functions and to permit growth and reproduction, excreting and exhaling waste output consisting of degraded, high-entropy materials, we still face a physicalist and thermodynamic definition.

The rise of metabolism as a paradigm to interpret the relationship between society and nature alludes to the old ontological fracture between teleology and mechanism, which in the field of social sciences is represented by the opposition between constructionism and realism (materialism). In its most general sense, materialism asserts that both the origin and development of what exists is dependent on nature and 'matter' (Swyngedouw, 2006). In other words, a certain physical reality exists prior to thought and to which thought must be related or interlinked (although it can never be identical to the real) (Foster, 2000). Moreover, we cannot overlook that somehow a nonhuman world could provide a foundational level of social morals and human ethics (Bookchin, 1992; Padovan, 1999, 2003). The morally good, the socially right, and the esthetically beautiful, are all understood as derived from certain physiological functions of associate living organisms. They are no longer the result of an abstract categorical imperative but of concrete social, nonhuman and human, practices (Bauman, 1993; Kropotkin, 1924).

Hans Driesch was one of the more prominent biologists and philosophers to promote vitalism in biology and claim the self-oriented organization of living organisms. He saw *entelecheia* as an organizing power (Driesch, 1908: 16). The main question of vitalism is how order can reconstruct itself from disturbance and whether the processes of life can properly be called purposive. According to Driesch, to describe a process as purposive, it must be connected with the idea of an end. It is thereby implied that the concept of teleology extends to many processes of very different types, and also that it is initially limited to the organic, at least insofar as so-called natural objects in the narrower sense are concerned. Relation to an end implies two things: first, the special adaptation of the process in question to an end (or better, its position in a system of objects thus typically adapted); and second, its appearance in an indefinite number of individuals or examples, in short, its unlimited plurality. This postulates that nature is fulfilled in organic natural bodies, and at first, only in them. We can therefore describe many biological processes as purposive (Driesch, 1914, p. 3).

However, despite Driesch's attempt to give living systems a purposive character (for example, in the light of the process of adaptation), it is unquestionable that a profound difference remains between the two even though one might say that there would be no consciousness or social life without (biological) life. There is a sharp distinction between meaning and life as different principles of organization.

In the case of a living organism, the exchange of matter and energy with the environment is oriented to a simple nonteleological reproduction of the organism itself. Modalities of recovery and transformation of the necessary elements for the reproduction of the organism's life change very slowly in time; above all, when they reach a balance, they are maintained over time. As the sociologist Eugenio Rignano has stated, the life and metabolism of cellular organisms are built up and maintained through a series of mechanical movements, through circulation and osmoses of liquid and gaseous substances, and through chemical reactions—all carried out within a mechanism of extremely complex structure. This mechanism tends to remain almost immutable during a long life-period, precisely because these vital phenomena have as their principal function the maintenance of the organism in as stable a condition as possible rather than the modification of the mechanism (Rignano, 1928).

Please cite this article as: Padovan, D., Metabolic exchanges and practices of regulation: The assemblage of environment and society in early social sciences, Ecological Informatics (2014), http://dx.doi.org/10.1016/j.ecoinf.2014.02.006

ARTICLE IN PRESS

Societal metabolism is not oriented to an equilibrium condition, but to continuous growth. Most social scientists have commented that there are no limits to the growth of a whole social system. The metabolic process between society and nature should provide structures made up of the surviving material products of humanity's work. Political economy denotes this ensemble by the word "capital": e.g., private dwellings, public edifices, cultivation of the soil, industrial establishments, machines, raw materials for industry, chattels for the satisfaction of the human needs, roads, bridges, and canals. The totality of these infrastructures might be designated as the *artificial telluric factor* or the *physical-technical structure* (Rignano, 1928). Indeed, in social systems meaning, consciousness, power, coordination and communication are mingled to build a purpose-oriented reproduction of a system itself, aspects that are not contemplated by living systems. Social systems regulate their own metabolisms with different tools that change over time: religions, wars, laws, wealth, techniques, and other typically social tools.

As Maurice Godelier suggests, in contrast to other social animals, human beings do not just live in society, they produce society for the purpose of living. In the course of their existence, they invent new ways of thinking and of acting—both upon themselves and upon the nature that surrounds them—therefore producing culture and creating history. Human beings have a history because they transform nature (Godelier, 1986).

The asymmetrical evolution of social and natural systems poses the problem of the impossible temporal and ontological synchrony between them. Thus, we need a definition of metabolism that combines blind mechanisms and intentionality, purposelessness and teleology, and humans and nonhuman agents' reproduction. On a systemic level, i.e., the phylogenetic level, this definition might foster a science of metabolic processes. All of the social processes and practices that make societal metabolism possible, their variable combinations, their characteristics of exteriority, heterogeneity and contingent necessity (obligatoriness), might be seen as an assemblage that goes beyond the functional and mechanical category of "industrial metabolism" as developed over the last twenty years (Ayres, 1989; Ayres and Simonis, 1994; Greadel and Allenby, 1995; Janssen, and van den Bergh, 1999; Janssen et al., 2001). In a certain sense, we can say that blind mechanisms and teleological purposes are to be considered using a dialectical and coevolutionary approach, as both interconnected and reciprocally influenced.

4. Early attempts to develop a science of metabolic processes

Whereas early social scientists easily dealt with physical nature, contemporary sociologists still struggle to investigate interfaces among society, nature and matter so as to understand an object of research, the nonhuman nature, that could justify a sociological approach. Perhaps the cultural constructivism of social sciences is not enough to understand and imagine society's course. Sociology is concerned with understanding environmental problems as socially constructed "dilemmas", but in doing so it diverts attention from the connections between social practices and ecological changes. Material, natural and nonhuman facts must enter the analysis.

The decoupling of society and nature was not previously included in writing about the evolution of social sciences. Sociologists such as Émile Durkheim and Max Weber, even though they reached the conclusion that modern social organisms are not only very different from plant and animal organisms but also that society and nature must be separated at the level of theoretical and empirical investigation, were at the same time aware that social science must admit nonhumans into its field of research.

In a very caustic overview of Wilhelm Ostwald's book on social energetics (Ostwald, 1909), Max Weber observed, "Although the foregoing observations might have given the impression that I believe the energetic viewpoint to be completely unfruitful for our discipline, this is not my view. It is entirely proper at some time to take into account the physical and chemical balance sheets of technical and economical developmental processes… We could benefit from his discussions as well, and certainly his general comment that it is necessary to take into account all of the statements that result from the application of the laws of energy to social phenomenon, deserves our unreserved agreement" (Weber, 1984, 49–50; see also Martinez-Alier, 1987, pp. 183–92). There Weber acknowledged that contribution by the physical sciences was needed to understand social phenomena, but in all of his own work, he insisted on the functional separation of the social and natural realms.

Émile Durkheim sculpted a sociology in which the constraint of social facts exercised upon individuals seems very analogous to the natural facts shaping societies. Moreover, he was aware, as were all of his contemporary sociologists, that physical conditions shape societal evolution. However, he built a sociology in which the social was clearly separated from the natural. Durkheim claimed a very clear and rightful distinction between these two types of coercion from the physical and social worlds: "There is a world of difference separating a physical from a moral environment. The pressure exerted by one or several bodies on other bodies or even on other wills should not be confused with that which the group consciousness exercises on the consciousness of its members. What is exclusively peculiar to social constraint is that it stems not from the unyieldingness of certain patterns of molecules, but from the prestige with which certain representations are endowed" (Durkheim, 1982 [orig. 1893]). Consequently, he could claim, "even if every individual drinks, sleeps, eats, or employs his reason, and society has every interest in seeing that these functions are regularly exercised, these are not social facts. If therefore these facts were social ones, sociology would possess no subject matter peculiarly its own, and its domain would be confused with that of biology and psychology". According to Durkheim, there is in every society a clearly determined group of phenomena that are separable, due to their distinct characteristics, from those that form the subject matter of other natural sciences. Here, he states that there is a stable separation between natural and social phenomena.

When considering complex societies and nature, they have been studied in the light of a one-way causality from social to natural (Murphy, 1995). Early social scientists often considered human systems to be embedded in natural ecosystems; however, for contemporary social sciences that share the paradigm that separates the social from the natural, is normal to consider the latter as part of the overall social system. This approach typically scrutinizes the environmental impacts produced by human activity and the increase in external risks, but in doing so it externalizes the wisdom of the natural domain. A more realistic view should not only claim that the "natural" is deeply involved in all social forms (Williams, 1980) but also that social systems (or global capitalist systems) are primarily ecological regimes that aim to appropriate natural resources as if they were free gifts (Moore, 2011) and that are increasingly reliant on the nonhuman world. As proposed by Michel Goldman, it is not only society that should be investigated as constitutive of nature and vice versa but also nature must be understood as an actor with a materiality that is sometimes joined with and sometimes autonomous from society (Goldman and Schurman, 2000). In other words, just as socially constructed truths help legitimize and facilitate the appropriation of nature, so do changes in materiality alter the way in which societies construct truths. For instance, the availability of cheap oil fosters myths of unlimited material abundance and growth (Redclift, 2009). The metabolic approach might present sociology with a valid alternative for reassembling society and nature.

Defining society as a metabolic system might be considered to be an undeserved simplification because it risks hiding singularities in the cauldron of statistics relative to the appropriation, transformation, consumption, and ejection of natural resources. However, the fact of using such an analogy to give an account of the functioning of a social system is theoretically plausible (Burkett, 1999; Dickens, 2004; Fischer-Kowalski and Haberl, 1998; Foster, 1999; Haberl et al., 2004; Hayward, 1994; Moore, 2000; York et al., 2003).

Please cite this article as: Padovan, D., Metabolic exchanges and practices of regulation: The assemblage of environment and society in early social sciences, Ecological Informatics (2014), http://dx.doi.org/10.1016/j.ecoinf.2014.02.006

Studying the society/nature complex from the metabolic point of view inserts into the old abstract knowledge of nature formalized by natural sciences and based on analogical thought a materiality and realism that resides in the space/time sphere of human practices. Neither people nor scientists are the producers of the abstract knowledge of nature, but their mutual actions on the frame of the temporal sphere comprehend nature itself. The materialism of this approach derives from the assumption that human history belongs to natural history and is dominated by material necessities. When these necessities take a social or socialized form mediated by human labor, nature is prolonged in the form of human history (Sohn-Rethel, 1978).

Due to this historical trait, social metabolism undergoes continuous transformations. It implies not only a quantitative study of the exchanges that take place between society and the natural environment (we do not discuss other societal environments, such as individual minds) but also an analysis of both changing agents and sociotechnical arrays that occur in metabolic exchange, making such an exchange possible. These assemblages of agents and attendants might be called infrastructures, which are the principal interfaces between culture and nature, "the boundary across which the ecological, chemical, and physical restraints to which human action is subject interact with the principal sociocultural practices aimed at overcoming or modifying those restraints" (Harris, 1979: 57).

Given the set of practices, knowledge, and artifacts that constitute the social infrastructure that makes metabolism possible, it is notable that there is almost no sociology of metabolic mechanism and exchange, i.e., the manner in which social agents of any type (governments, markets, communities, groups, experts, companies, organizations, and households) manage, manipulate, produce and consume nature. The study of the metabolic profile of the systems that we consider and practices put in place to transform matter and energy into objects to be consumed tells us a great deal about the characteristics of those systems (York et al., 2003; Martinez-Alier, 2004). The metabolic perspective gives us an analytical understanding of society that reintroduces the "material" in the sociological reflection. As previously noted, Frédéric Le Play, reconciling the human need for socialization and quality of life depends on the "productive energy of natural forces" (Le Play, 1879, vol. I: 79).

A sociology of metabolic processes has already been designed, not only at a theoretical level but also at the level of operational complexity. In an unknown book dedicated to statistics (Geddes, 1881, cf. Also Martinez-Alier, 1987), the zoologist and botanist Patrick Geddes proposed to classify social facts according to a modality very similar to the metabolic perspective that we discuss here. According to Geddes, first a society exists within certain limits of time and space; second, it consists of a given number of living organisms; third, those organisms change nature around them, essentially appropriating part of its matter and energy; and fourth, they use this material and energy for sustaining their lives, for example, to support their physiological functions. Geddes defined these propositions as "sociological axioms", principles that not only constitute detailed indicators for the identification of the metabolic profile of a society to set up an input–output model as has been suggested by Martinez-Alier (2004) but are also able to implement important knowledge bases for the foundation of a materialist sociology. These axioms allowed classifying the social facts as follows (Geddes, 1881, p. 12):

- Those relating to the limits of time and space occupied by a given society.
- Those relating to the natural matter and energy utilized by that society.
- Those relating to the organisms composing the society.
- Those relating to the application of the utilized matter and energy by the given organisms.

It is clear that no attempt is made by Geddes to completely define a society. A society may be much more than all of this, in which case more general truths are discoverable, but in any case these four generalizations are obviously true, neither hypothesis nor metaphysical principles being involved. Henceforth, these generalizations are denoted as sociological axioms.

The classification of social facts suggested by Geddes has little to do with the similar definition of "social fact" that Durkheim proposed twenty years later, which is totally based on sociocultural and organizational phenomena, aspects of sociological analysis that must not be excluded. The proposal of Geddes is almost completely oriented towards recognizing the use of land and environment, along with measuring their scarcity due to natural events or social actions such as the discovery, conquest, or colonization of land. Even the consumption of energy and matter constitutes an objective measurement because they are considered the main modes through which raw material and energy are transformed into objects to be consumed. The process of the transformation of raw materials identified by Geddes is generally composed of three stages: the first, called exploitation, includes agriculture, mining and applied engineering; the second is that of manufacturing; and the third is that of movement by agencies of transport and exchange to the place where the raw materials are ultimately provided to fulfill society's desires for protection, alimentation, and nervous stimulus. Geddes added one final form of the consumption of raw material present in more complex societies, "intermediate products," which concern the conversion equipment involved in the service of exploitation, manufacturing and transport. An important part of energy and matter is thus dissipated in the course of various stages of production without being directly used and therefore lost. Here there is already a clear idea of the indirect consumption of energy and materials associated with the consumption of goods and primary products, and this consumption is classified on the basis of different forms of an organism's adaptation to its environment.

The fact that adaptation becomes dominion remains a vivid issue. Modern systems theory has somehow revived the Spencerian tradition that sees the environment not only as a resource to care for but also a complex of physical resistance to overcome and break down in the logic of competition for the expansion and growth of dominant systems. These positions are obviously not unique, but we can say that the social system is the dominant actor in a set of asymmetrical relationships between a system and its environment. The system is the subject that reduces the complexity of the environment to stay alive, which describes the environment for its own purposes, which acts on the environment to reduce its own uncertainty, which projects the internal chaos to regain stability onto the environment.

However, in doing so, a system creates the conditions for an increase in its own uncertainty. From the sociological perspective, the system appropriates its environment exclusively for its own purposes, creating a curtain of ignorance about the consequences of subtracting the environment's life-support systems. A metabolic vision has the potential to overcome the neo-social-Darwinism or sociobiological approach, to develop a critical sociology of the processes of appropriating and colonizing nature.

4.0.0.1. Human labor as metabolic activator. Albert Schäffle is among the sociologists who best interpreted social metabolism. Coming from the school of the so-called "socialism of the chair", he believed that each activity of a social body's components—small or large—presupposes a "fund" (Vorrath) of labor in the form of people and goods. Any concrete work consumes a part of this "fund" of force, necessitating renewal. The social body thus demands an exchange of matter through all of the social body's parts and functions: production, circulation, distribution, exchange, and the use and disposal of materials necessary for maintaining personal and institutional social units (Schäffle, 1896).

Indeed, continued Schäffle, every day an immense mass of the materials and the energy of nature are, through labor, appropriated by the social body to be adapted to its needs through production and then distributed to the social body's various parts through circulation;

Please cite this article as: Padovan, D., Metabolic exchanges and practices of regulation: The assemblage of environment and society in early social sciences, Ecological Informatics (2014), http://dx.doi.org/10.1016/j.ecoinf.2014.02.006

ARTICLE IN PRESS

transformed into the social fabric by means of absorption (as for food) by both institutions and individuals, and returned into the lap of nature through the consumption of goods and bodily forces. Thus, Schäffle clearly outlined the mechanism of social metabolism by means of which energy and matter that exist in nature enable the social body to maintain itself. Furthermore, the exchange of materials not only serves as a means of conserving the bio-organic substratum of society, i.e., conserving biological bodies, it is also indispensable for maintaining the extraorganic parts of the social body, i.e., the functions of social life, the spiritual, religious, cultural and symbolic aspects that cannot exist without an exchange of materials. Although still at an elementary stage, Schäffle recognized and very clearly described the ecological interdependence of society and nature.

The economic and physiological exchange of material does not entail the destruction of material and energy, but rather, entails their reorganization into sources of energy and institutions, which make their social use possible. Essentially, Schäffle applied thermodynamic principles to social exchanges. According to these principles, energy and matter are not destroyed, but are only transformed, disorganized and then reorganized for other uses. An efficient mechanism of social metabolism can neither allow any energy to be lost nor permit increasing entropy; the result would be a crisis within the social organism itself.

Schäffle distinguished between a *progressive* and a *regressive* exchange of materials or matter. The former corresponds to the production and manipulation of raw materials; the second to the consumption and elimination of used materials (i.e., waste/rubbish/garbage). This distinction renders the social exchange of material that is carried out by the human community unique, different from that of animals and plants. Although the organic process of transforming materials is similar in humans and other animals at the bodily level, Schäffle quite rightly argued that the social economics of the exchange of materials is very different from the natural economy of exchange as practiced by other organisms.

The economic regulation of social metabolism depends on the conscious, societally developed needs and reasons. According to Schäffle, socially manipulated goods, other than raw materials, contain a *quid* of uniqueness, spirituality, rationality, work and social techniques that make them completely different from the goods required for animal life. Traces of Marxist thought seem to hover around these words. Work makes the social exchange of materials possible and work is, at a high level, conscious, spiritual, and guided by rationality. The rational activity of intelligence, feeling, and will, makes nature's energy and matter available to humans, modifying, disorganizing and reorganizing both energy and matter to meet humanity's specific needs. Thanks to agriculture and animal husbandry, the same process for the production of food rationally dominates nature's entire organic kingdom: nutrition becomes both rational agriculture and culinary art.

I do not wish to advance this reflection on Schäffle's social metabolism any further: it speaks for itself. I only wish to add to concepts that Schäffle used to explain social economy. The first of these concepts is *nature*, which he meant as a "font or spring" and as the "place of dejection/evacuation" for the exchange of matter. Nature was one of the three factors of production identified by Schäffle that can be associated with labor and capital (Schäffle, 1896: 974). Nature demonstrated two contrasting aspects in its relation with social labor: on the one hand, resistance to the use of its resources and energy which had to be overcome through the rational intelligence of human beings; on the other, however, nature could be of help to society without this help having to be exchanged with social labor. Schäffle here referred to light, heat, rain, and the air we breathe, that is, a group of "free goods" (res communes) that have recently been defined as "services supplied free of charge by the ecological systems of society for the proper functioning of the support system of life on Earth". The second concept is that of *scarcity*. For Schäffle, both quantitative scarcity and the qualitative lack of natural resources are the basis of all need, and thus of the social economy of exchange, which is effectively a complex means of satisfying needs. The third concept is that of *labor*, in the broadest physical meaning of the word: every effort made by living forces, every use of this living force. According to Schäffle, the labor of every person and every service (utility) supplied by a thing, every service and every personal use, is labor. This definition is quite close to that of Lilienfeld. For him, labor is the combination of the physiological forces of natural organisms and the forces of human bodies or, to use another formula, the combination of matter and force (Lilienfeld, 1896).

The metabolism pattern is only a fragment of the complex structure of Schäffle's sociological theory. That theory does not add much to what Spencer previously outlined, but it provided a new reading corner with the goal of incorporating the reality of the social body into a synthetic system analogy. The distinction between Spencer and Schäffle is perhaps more subtle, as Albion Small commented: "The difference reduces to this: Spencer does not succeed in making his interpretation of society picture it as more than an *organization of mechanisms*. Schäffle's central conception of society is of an *organization of work*" (Small, 1905: 167). Although mechanism implies work and work implies mechanism, it is interesting to note that the extension of the concept of "function", which was used by Schäffle to represent metabolic and reproductive work and was closely related to energy and matter consumption, puts his work on a higher plane than that of Spencer. In short, Schäffle outlined not only "how" men and women are associated but also "what men and women do" through these structures.

5. Labor as practice for assembling society and nature

The thoughts of Schäffle, Small and Worms enable us to open the chapter on social labor, practice and activity as the unique medium between society and nature. Social metabolism or the resource throughput between physical nature and human society is activated and mobilized by labor. As suggested by Swyngedouw (2006), the metabolic process is energized by fusing the physical properties and creative capacities of humans with those of nonhumans. It is through labor that raw materials are transformed into use values and are given a specific exchange value due to their capacity to be exchanged. As Marx suggested, without inputs of concrete labor (or energy to drive machines that replace concrete labor) there is no metabolism.

> "The labor process, as we have just presented it in its simple and abstract elements, is purposeful activity aimed at the production of use-values. It is an appropriation of what exists in nature for the requirements of man. It is the universal condition for the metabolic interaction *[Stoffwechsel]* between man and nature, the everlasting nature-imposed condition of human existence, and it is therefore independent of every form of that existence, or rather it is common to all forms of society in which human beings live". (Marx, 1976 (orig. 1867): 290)

Although labor changes over time, it remains the main action that appropriates and transforms nature while producing wealth. First, labor is an appropriative action implied in practices of selecting, extracting and relocating natural elements, putting them at the disposal of other practices (Benton, 1989). The array of services freely provided by nature and freely appropriable and usable by society (such as biomass or nitrogen) can be counted as pure appropriation. These ecosystem services, which have become a diffuse concept for attracting attention to societal dependence on ecological life-support systems (Daily, 1997; De Groot et al., 2002; Gómez-Baggethun et al., 2010), provide one of the clearest examples of the free metabolic exchange between society and nature. As suggested by Marx:

> "All of those things that labor merely separates from immediate connection with their environment are objects of labor spontaneously provided by nature, such as fish caught and separated from their natural element, namely water, timber felled in virgin forests, and ores extracted from their veins" (Marx, 1976 (orig. 1867): 284)

Please cite this article as: Padovan, D., Metabolic exchanges and practices of regulation: The assemblage of environment and society in early social sciences, Ecological Informatics (2014), http://dx.doi.org/10.1016/j.ecoinf.2014.02.006

ARTICLE IN PRESS

In contrast, agricultural labor processes are primarily deployed to sustain or regulate the environmental conditions under which seeds or stock animals grow and develop. There *is* a transformative moment in these labor processes, but the transformations are brought about by natural organic mechanisms, not by the application of human labor (Benton, 1989, 67–68). Finally, we have a concept of the labor process, central to which is the notion of a raw material undergoing a transformation to yield a use value. This transformation is the outcome of human labor that involves the utilization of raw materials and instruments of labor to achieve its purpose. The process involves both human intentional activity and a range of distinct materials, substances and other nonhuman beings and conditions.

Even though these distinctions are useful for analysis, it is apparent that under capitalistic conditions, these types of labor are all distinctively human rather than purely natural and unmediated forms of activity in that, in their human forms, are intentional, socially organized and usually involve the use of tools such as techniques, science, and expert knowledge (Sayers, 2007).

In this view, labor is a peculiar and vexing variety of human activity, a special act that makes society an organized and oriented texture of functional human activities performed by human agents. Labor is embedded in complex arrays of human activities that we call practices. Practice is the intentional and oriented transformation of matter and of living organisms' reproduction. We might say that labor is an activity and practice that is special and transformative, the transformative taking on the world. In Marxist terms, practice is human action that involves the transformation and conservation of matter (Foster, 2000). All practices produce something. In the purely material dimension, because practices always require some material as an input, they also produce something material as an output (Ollinaho, 2012) Material production is Marx's very starting point:

> "Labor is, first of all, a process between man and nature, a process by which man, through his own actions, mediates, regulates and controls the metabolism between himself and nature. He confronts the materials of nature as a force of nature. He sets in motion the natural forces that belong to his own body, his arms, legs, head and hands, to appropriate the materials of nature in a form adapted to his own needs. Through this movement he acts upon external nature and changes it, and in this way he simultaneously changes his own nature." (Marx, 1976 (orig. 1867): 283)."In the labor process, therefore, man's activity, via the instruments of labor, effects an alteration in the object of labor that was intended from the outset. The process is extinguished in the product. The product of the process is a use-value, a piece of natural material adapted to human needs by means of a change in its form. Labor has become bound up in its object: labor has been objectified, the object has been worked on." (Marx, 1976 (orig. 1867): 287)

The conditions of recruitment, provision and organization of labor have changed over time. As suggested by Robert Kurz, in contrast to premodern societies, the "process of metabolism with nature" is no longer codified by religious traditions and traditional grammars, but is now mediated through the mechanism of the market, which progressively incorporates the whole relation to nature by the process of abstracting the commodity form. Capitalism entails the transformation of the material and substantive content of reproduction into "abstract things", whose phenomenal form is money indifferent to that content. Paradoxically, the process of abstraction of labor renders men much more dependent on social relations within the "process of metabolism with nature" than they were in premodern society, which was characterized by small, autarchic units of production (Kurz, 1994).

If metabolism is nothing more than the continuous process of assembling and reassembling past and present matter and labor, where labor is energy transferred to a human organism by means of nourishing matter, under capitalist social relations the separation of society from nature is accomplished, but only to subsume it under new forms of exploitation. While separation is at work it allows the *forced unity* of the society/nature complex ascribed by dualistic ways of thinking to each term. Thus, under the term "production of nature", we can see the dialectical movement between separation and unification of the society/nature complex (Benton, 2001; Castree, 2001; Moore, 2009).

The subsuming process arises, as Kurz notes, out of a blind *social machine for the abstract utilization of labor power* that tends to absorb within its vacant movement man, nature and everything else that it touches, directing them and later evacuating them into the other dead form of labor and matter without adding any other qualitative end. This social machine must put *material quality* into motion: raw materials, natural forces and living human labor; such qualities, however, do not constitute a goal nor do they produce any end by themselves, they are only means in the tautological and self-referential process of abstract labor. There is, therefore, a reversal of the means and the ends: labor is no longer a means towards the qualitative end of the appropriation of nature, but on the contrary, the qualitative and material appropriation of nature is only an indifferent means for the process of changing the form of abstract labor as an end in itself (Kurz, 1991).

Currently we can speak of complex systems of appropriation of materials, energy and labor from nature (physical, nonhuman and human nature) and of systems that transform the latter to provide goods, commodities and services indifferent to their uses. Here, labor and nature appear as objects of manipulation separated and detached from the social realm. A careful examination might suggest the idea that these systems of appropriation/provision are primarily practical systems in which expert organization and knowledge are the leading players that rule huge arrays of social labor and knowledge enacted by individuals connected through different social configurations. These systems of routinized practices are very important for social sciences, as suggested by Giddens:

> "The basic domain of the study of the social sciences, according to the theory of structuration, is neither the experience of the individual actor nor the existence of any form of societal totality, but social practices ordered across space and time" (Giddens, 1984: 2).

As Giddens suggests, through social practices that are reproduced across time and space, agents generate patterns of social relations that are characterized as social systems. In and through their activities, agents reproduce the conditions that make these activities possible. Social systems are thus relations among actors, organized as recursive social practices and reproduced and transformed by the actors. Systems are said to have structural properties or institutionalized features, giving 'solidity' across time and space (p. 24).

However, Giddens forgets that expert managements and organizations are the true rulers of these social practices and of social metabolism. Human labor, practices and activities, which are the main interface that allows society to appropriate and transform nature, are prevalently ruled and mobilized by expert organizations. These organizations set up the way in which nature is transformed, accumulated, produced, and colonized for the purpose of satisfying the needs of driving economic forces that provide consumers with continuing changing use-values and a market of exchange-values. These systems of exchange between nature and society are planned and regulated by these expert organizations based on technical knowledge, expert practices and labor and scientific and rational knowledge. These types of activities and expert practices are more rational and scope oriented than are those practices ruled by habits and recursiveness. Expert systems are systems of technical accomplishment or professional expertise that organize large areas of the material and social environments in which we live today and that organize almost the totality of social metabolism. In short, expert systems are systems of technical accomplishment or professional expertise that organize and rule large areas of the material and social environments in

Please cite this article as: Padovan, D., Metabolic exchanges and practices of regulation: The assemblage of environment and society in early social sciences, Ecological Informatics (2014), http://dx.doi.org/10.1016/j.ecoinf.2014.02.006

ARTICLE IN PRESS

which we live today (Giddens, 1990). Once more, we find the earth to be a universal instrument, for it furnishes a locus standi to labor and a field of employment for its activity (Goodman, 1999).

6. Metabolism as appropriation

The process of appropriation of nature is neither neutral nor natural. It is a purposeful process that is mediated, as we have seen, by social labor, which means a complex array of scientific and common knowledge, technical and communicative tools. The process by which human society appropriates nature for its own ends is completely different from the process by which other living organisms take possession of the same natural resources. Furthermore, different historical societies appropriate nature with different tools, goals and reasons. However, the "problem of appropriation" is a mixed social/natural mixed, with all of its scientific, political and moral implications.

All scholars agree that from a historical perspective, society/nature metabolism is the particular form in which societies establish and maintain their material input from and output to nature; i.e., the mode in which they organize and regulate the exchange of matter and energy with their natural environment (Fischer-Kowalski and Haberl, 1994; see also Ayres, 1989; Ayres and Simonis, 1994; Ayres, 1997; Janssen et al., 2001; Erkman, 1997).

However, at the level of its historical forms, social metabolism appears as a peculiar complex of physical processes and socioeconomic activities marked by waves of growth and decline. Cycles of expansion and contraction are typical of societal metabolism historical dynamics, demonstrating their unstable equilibrium. However, these cycles are not only shaped by the physical conditions of resource appropriation but also by social and political actors and their often-turbulent relationships to rule that appropriation. The mode in which society organizes and regulates its own metabolism depends not only on the physical state of appropriable resources but also on social–property systems, social conflicts on surplus distribution, long-term demographic and commercial trends, development of productive forces, and balances of class forces (Brenner, 1977; Pomeranz, 2000). The political regulation or ecology of metabolism is deeply affected by the way in which society is hierarchically stratified. For example, the slave trade fostered by European countries created a new type of periphery that enabled Europe to exchange an ever-growing volume of manufactured exports for an ever-growing volume of land-intensive products (Pomeranz, 2000). The trade of enslaved people molded the European metabolism and the way in which it was ruled. Thus, I might say that metabolism is a matter of social and political—not only physical—investigation aimed at identifying agents of regulation, their reciprocal connections, and their ability to cope with resources appropriation.

Some of the scholars that we discuss in this paper were persuaded that the process of adaptation of an organism to its environment prevents society from becoming an agent of exploitation or conquest. However, the exchange of matter and energy between a social system and its environment is not only oriented to simple mechanical reproduction of the system itself, as in the case of individual metabolisms or ecosystems. In these cases, modalities of recovery and transformation of elements for the reproduction of the organism change very slowly over time and above all, when they reach a balance, it is maintained over time. The social or socioeconomic metabolism is not instead directed to a state of equilibrium, but to increasing growth. It is the historical features of metabolic regulation that, under capitalist conditions, lead towards constant growth and accumulation

From this perspective, the metabolic relationship between social and environmental systems acquires the form of appropriation, colonization, accumulation or domination. However, here I do not give terms such as appropriation or colonization a neutral—and therefore analytical—meaning, as is common in the metabolism literature (See Fischer-Kowalski and Haberl, 1998; Martinez-Alier, 2002). In my view, these types of social operations are rationally oriented and motivated (Moore, 2000). It is not a secret that the elaborated scientific knowledge and practice in the capitalist society are oriented towards the control, manipulation, and domination of the (broadly speaking) "other" (nature) (Pellizzoni, 2011). Appropriation of nature means that man manipulates it for his own goals, makes it similar to himself, and assimilates it. The material appropriation of nature happens through labor and consumption: nature is marked by human form or is integrated by the human body (Böhme and Grebe, 1992). Societies organize their resource throughput purposively, even changing parameters of natural processes to gain better access to nature's resource supply (Schandl et al., 2002).

The process of appropriation and transformation of nature in "appropriated nature" implies the following phenomena that should be the object of reflection by social sciences because they represent crucial socio-technical-material interfaces between society and nature:

1. The technological multiplication of the society–nature metabolism that carries over to increasing consumption of natural resources for the purpose of extracting and consuming other indispensable resources such as food.
2. The endless growth of the rate of consumption of raw materials and primary sources of energy, reaching an unthinkable peak of consumption and forcing the issue of resource renewability.
3. The unending increase in the conversion of matter and energy, to the point of reaching dimensions comparable to geophysical and biological global processes (e.g., the consumption of CO2 stored in the ground and its release into the atmosphere).
4. The development of knowledge about the natural mechanisms of reproduction that implies a consequent debugging of technological devices able to regulate, transform, and alter such mechanisms of ecosystem services reproduction.

Reflecting on the basis of metabolic horizon means that sociology should be applied to the study of the interaction of man and nature as "natural processes socially organized." As seen above, Karl Marx realized that the process of capitalist production based on socially useful labor is the main medium of interchange between society and nature. The process of appropriating nature suggests the following reflections:

- The process is essentially "material", nothing idealistic appears in this situation and the set of social practices is designed to monitor and regulate the powers of nature. This process involves the laborer's use of the mechanical, physical, and chemical properties of some substances to make other substances subservient to his aims.
- The process of appropriation is historically determined, changing according to the basic degree of societal development, in other words, on the basis of the progress of work and technical processes, as noted by sociologists of the time. The metabolic process thus indicates the socio-technical complexity of social systems.
- Finally, the process of capitalist accumulation disturbs the metabolism between man and earth, which is the return to the land of the natural resources consumed by various forms of livelihood. "Capitalist production" collects the population together in great centers and causes the urban population to achieve an ever-growing preponderance. This has two results. On the one hand, it concentrates on the historical motive power of society; on the other hand, it disturbs the metabolic interaction between man and the earth, i.e., it prevents the return to the soil of its constituent elements consumed by man in the form of food and clothing; thus, it hinders the operation of the eternal natural condition for the lasting fertility of the soil. Therefore, it destroys at the same time the physical health of the urban worker and the intellectual life of the rural worker… Capitalist production, therefore, only develops the techniques and the degree of combination of the social process of production by simultaneously undermining the original sources of all wealth—the soil and the worker (Marx, 1976: 637–638).

Marx's position was never adequately investigated in the field of political economy, but it found an indirect and unreported reception

Please cite this article as: Padovan, D., Metabolic exchanges and practices of regulation: The assemblage of environment and society in early social sciences, Ecological Informatics (2014), http://dx.doi.org/10.1016/j.ecoinf.2014.02.006

ARTICLE IN PRESS

among sociologists, ecologists, biologists, and geographers. Some noted that evolution had transformed man from a "brute creature" in competition with other animals to a dominator of the planet, able to subdue the earth for his needs. The birth and development of social systems, built up by civilized men in the image of their biological individuality, led to negative consequences both for nature and for society.

Benjamin Kidd stressed that the fight for survival that was the basis of the evolution of social systems led to the disappearance of entire civilizations and indigenous peoples, along with the irrational appropriation of a large amount of natural resources (Kidd, 1894). According to Kidd, Anglo-Saxons exterminated the less developed peoples with whom they had entered into competition, not only through bloody wars of extermination but also by imposing laws that were no less deadly. However, perhaps the main weapon of Western civilization has been its occupation of native territories to exploit natives' resources. Although Kidd was not aware of doing so, his work was a moralizing but clear description of the era of European ecological imperialism later described in brilliant colors by Alfred Crosby (Crosby, 1986).

Kidd referred to a phenomenon that geographers of the same period reported: *Raubwirtschaft*. The *Raubwirtschaft*, literally "predatory economy" (Raumolin, 1984), is the negative side of social metabolism. The term refers to local distortions in the balance of nature caused by industrial capitalism, but its use in nineteenth-century geography was essentially moral in nature, lacking a precise theoretical meaning. The geographer Ernst Friedrich was the first to express this concept, in which he assumed that a rational exchange of resources and energy between nature and society must ensure and enhance their durability. Human evolution in increasingly complex social systems can only increase the pressure on natural resources in a manner that is aggressive enough to cause serious imbalances. The main thrust of *Raubwirtschaft* comes from the social tendency to move, a phenomenon that involves the irreversible consumption of energy resources. This irrational consumption of resources affects not only mines, forests and agricultural land, as already noted by others but also human labor, which in turn may be a victim of Raubwirtschaft. According to sociologists discussed above, even Friedrich believed that resources exploitation leads to an increasing environmental awareness and to measures of regulation and protection of natural resources, but I believe that such optimism is tinged with hypocrisy and self-indulgence, not unlike optimism expressed currently.

Several natural and social scientists related *Raubwirtschaft* to the degradation of energy or entropy. Bernard Brunhes showed how human activity causes disorder in living nature and suggested to use the notion of entropy to indicate not only energy dissipation phenomena in nature but also processes of social degradation. Sociologists such as Eugène de Roberty addressed social energy, whereas intellectuals such as Rosa Luxemburg used the metabolic metaphor to argue that capitalist development is nourished by the destruction of precapitalist economic forms, inclusive of natural and human resources. More recently, such predatory activity has been called ecological imperialism (Foster and Clark, 2004).

To maintain their metabolism, societies transform natural systems so as to maximize their usefulness for social purposes. Natural ecosystems are thus replaced by agro-ecosystems designed to produce as much usable biomass as possible, or else they are converted into a space to be built. Animals are domesticated and the genetic codes of species are altered to improve their resistance to parasites and pesticides or to produce drugs. Next, "material–ecological" flows transform relationships between city and country and between global metropolises and the periphery. Some countries are robbed of their resources, transforming whole ecosystems upon which states and nations depend. Massive movements of population and labor that are interconnected with the extraction and transfer of resources are generated. Ecological wastes are dumped in ways that widen the chasm between the center and the periphery. Overall, a global 'metabolic rift' is created that characterizes the relationship between capitalism and the environment while at the same time limiting capitalist development.

These interactions between natural and social systems, however, cannot define metabolic exchanges of matter and energy. These modes of intervention in natural systems represent a real colonization, i.e., a set of social activities that deliberately change important parameters of natural systems and actively keep them in conditions different from those that would have arisen in the absence of such intervention. Colonization can be seen as a strategy to ensure the future availability of natural resources, which implies at the same time an extraordinary increase in cognitive and manual work and the exceptional development of an increasingly energy-consuming general intellect. The fate of humanity is caught in this dilemma: capitalist regulation and the accumulation of natural resources require an unlimited increase in consumption.

7. Conclusions

This article attempts to highlight how a metabolic approach to the relationship between society and nature is useful for sociological knowledge—it is more fertile than culturalist, symbolic and constructionist approaches. Many sociologists and naturologists of the nineteenth century were more than convinced that there were no definitive borders between their disciplines and that understanding society depends on nature and vice versa. There were no good scientific reasons to build such a deep ditch between the two scientific kingdoms—including the fact that the natural sciences grew faster than the social ones, even if true to a certain extent. Hermeneutics was invented precisely to fill the methodological gap between natural and human sciences to cause the objects of social research to reflexively talk. Kantianism, historicism and the culturalist idealism of late nineteenth century were most likely primarily responsible for this final separation that endures to this day, although it must be said that both Weber and Durkheim addressed problems very close to the environment, such as the agrarian question, social energetics, and the demographic impact on the physiology of the social organism. However, a history of this separation must still be thoroughly investigated, and that effort could bring to the surface some interesting issues related to the epistemological and ethical–moral aspects of the history of sociology, such as the long hegemony of raciological thought.

The fact that consumers are periodically asked about their environmental concerns does not add much to what we already know: namely, without radical policies, actions, and practices, social inertia does not move from its track, the path dependency established by disguised policies does not interrupt, shortsighted and unidirectional technologies are not replaced, and unequal social configurations remain hegemonic.

A metabolic model instead implies a close interdependence between nature and society, helps to explain the evolution of the social as deeply dependent on the natural, brings together nature and society on the horizon of consumption and transformation of matter and energy, and is able to typify different social forms based on the manner in which resources are extracted, processed, consumed and ejected. Metabolism, being the basic mechanism of all organic existence, also constitutes the first form of freedom (Jonas, 1966).

Further advancements in metabolic vision tell us that the process of exchange between society and nature has turned towards a variable process of interpenetration and intermingling between society and nature to build up new social hybrids or assemblages. The type of society/nature complex delineated by early sociologists could be seen as very close to the assemblage concept (DeLanda, 2006). DeLanda stated that what Gilles Deleuze calls "assemblages" is the main theoretical alternative to organic totalities, wholes characterized by relations of exteriority among the component parts of wholes such as social systems and ecosystems. These relations imply that a component part of an assemblage may be detached from it and plugged into a different assemblage, resulting in different interactions. In addition, Deleuze considers the heterogeneity of components to be an important characteristic of assemblages. Thus, the society/nature complex might be considered a

Please cite this article as: Padovan, D., Metabolic exchanges and practices of regulation: The assemblage of environment and society in early social sciences, Ecological Informatics (2014), http://dx.doi.org/10.1016/j.ecoinf.2014.02.006

ARTICLE IN PRESS

multifaceted and variable array of different assemblages that change over history in the relationship between sociotechnical and organizational conditions of social labor and practices delivered by it. When sociology became more rationalist and individualist, it lost this perspective, which linked society and nature while wishing to build a homogenous totality called society.

The metabolic approaches discussed here open interesting opportunities, both scientific and practical. A sociology of metabolic processes has the advantage of addressing the following aspects:

- Accounting natural resources, biodiversity and biocapacity that are actually consumed by the socioeconomic metabolism, providing some tools to evaluate the effectiveness of environmental policies.
- Reassembling a theoretical gap between production and consumption that has plagued the social sciences for decades, recognizing that from the environmental point of view, almost every practice, activity, or action involves the consumption of nature. Biotic consumption is intrinsic—almost like a metaphysical substance, although it is not—to both productive and social consumption.
- Identifying the complex interfaces between society and nature that sociology must investigate. This obviously means to identify the complex space full of practices, knowledge, discourses, techniques, technologies, and organizations that enable society and its subsystems to reproduce by appropriating natural resources. This space of "contact" between the social and natural systems is the system of social appropriation of nature as it has evolved throughout history and today pushes the apical points of colonization and appropriation, putting to work all human resources that are available in the social system.
- Avoiding importing biological models to explain social phenomena. The metabolic approach addresses exchanges between nature and society, but eludes the social biologicization that often surreptitiously creeps into attempts to combine the two worlds, as in the case of sociobiology. The study of the metabolic cycle is not intended to bend the functioning of the social to the necessity of natural laws, but rather to identify the simultaneous effects generated by the metabolic fracture or rift on natural and socioeconomic systems.

References

Ayres, R.U., 1989. Industrial metabolism and global change. Int. Soc. Sci. J. 41 (3), 363–373.
Ayres, R.U., 1997. Industrial metabolism: work in progress. Working Paper 97/09/EPSINSEAD, Fontainebleau, France.
Ayres, R.U., Simonis, U.E., 1994. Industrial Metabolism: Restructuring for Sustainable Development (Tokyo/New York/Paris).
Bauman, Z., 1993. Postmodern Ethics. Blacwell, Oxford.
Benton, T., 1989. Marxism and natural limits. New Left Rev. 178, 51–86.
Benton, T., 2001. Marx, Malthus, and the Greens: a reply to Paul Burkett. Hist. Mater. 8, 309–332.
Böhme, G., Grebe, J., 1992. Scienza sociale della natura. Sull'elaborazione scientifica del rapporto metabolico tra uomo e natura. In: Bosco, E. (Ed.), Ecologia e politica, Angeli, Milano, pp. 111–132.
Bookchin, M., 1992. A philosophical naturalism. Int. J. Pol. Ecol. 1 (2), 60–88.
Brenner, R., 1977. The origins of capitalist development: a critique of neo-Smithian Marxism. New Left Rev. 104, 25–92.
Burkett, P., 1999. Marx and Nature. St. John's Press, New York.
Castree, N., 2001. Marxism, capitalism, and the production of nature. In: Castree, N., Braun, B. (Eds.), Social Nature: Theory, Practice and Politics. Wiley-Blackwell, Oxford, pp. 189–207.
Comte, A., 1838. Cours de philosophie positive, vol. III. Bachelier, Paris.
Crosby, A.W., 1986. Ecological Imperialism. Cambridge University Press, Cambridge.
Daily, G.C., 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, DC.
De Groot, R.S., Wilson, M., Boumans, R., 2002. A typology for the description, classification and valuation of ecosystem functions, goods and services. Ecol. Econ. 41 (3), 393–408.
DeLanda, M., 2006. A New Philosophy of Society: Assemblage Theory and Social Complexity. Continuum, New York.
Dickens, P., 2004. Society and Nature. Polity Press, Cambridge.
Driesch, H., 1908. The Science and Philosophy of the Organism. Adam and Charles Black, London.
Driesch, H., 1914. The History and Theory of Vitalism. MacMillan & Co, London.
Durkheim, É., 1982. The Rules of Sociological Method. The Free Press, New York, London (orig. ed. 1893).
Erkman, S., 1997. Industrial ecology: an historical view. J. Clean. Prod. 5 (1–2), 1–10.
Fischer-Kowalski, M., 1998. Society's metabolism. The intellectual history of materials flow analysis, Part I, 1860–1970. J. Ind. Ecol. 2 (1), 61–78.
Fischer-Kowalski, M., Haberl, H., 1994. On the Cultural Evolution of Social Metabolism with Nature. Schrift. Soz. Ökol, Iff Vienna p. 40.
Fischer-Kowalski, M., Haberl, H., 1998. Sustainable development: socio-economic metabolism and colonization of nature. Int. Soc. Sci. J. 158, 573–587.
Fischer-Kowalski, M., Hüttler, W., 1999. Society's metabolism: the state of the art. The intellectual history of material flow analysis, Part II: 1970–1998. J. Ind. Ecol. 2 (4), 107–137.
Foster, J.B., 1999. Marx's theory of metabolic rift: classical foundations for environmental sociology. Am. J. Soc. 105 (29), 366–405.
Foster, J.B., 2000. Marx's Ecology: Materialism and Nature. Monthly Review Press, New York.
Foster, J.B., Clark, B., 2004. Ecological Imperialism: the curse of capitalism. In: Panitch, L., Colin, L. (Eds.), Socialist Register 2004: The New Imperial Challenge, pp. 186–201.
Fouillée, A., 1890. L'évolutionnisme des idées-force. Alcan, Paris.
Fouillée, A., 1905. Les éléments sociologique de la morale. Alcan, Paris.
Geddes, P., 1881. The Classification of Statistics and its Results. Adam and Charles Black, Edinburgh.
Giddens, A., 1984. The Constitution of Society. Polity Press, Cambridge.
Giddens, A., 1990. The Consequences of Modernity. Polity Press, Cambridge.
Giddings, F.H., 1896. The Principles of Sociology. MacMillan, London.
Godelier, M., 1986. The Mental and the Material. Verso, London.
Goldman, M., Schurman, R., 2000. Closing the "great divide": new social theory on society and nature. Annu. Rev. Soc. 26, 563–584.
Gómez-Baggethun, E., de Groot, R., Lomas, P.L., Montes, C., 2010. The history of ecosystem services in economic theory and practice: from early notions to markets and payment schemes. Ecol. Econ. 69, 1209–1218.
Goodman, D., 1999. Agro-food studies in the "age of ecology": nature, corporeality. Biopolitics. Soc. Rur. 39 (1), 17–38.
Greadel, T.E., Allenby, B.R., 1995. Industrial Ecology. Prentice Hall, Englewood Cliffs,New Jersey.
Haberl, H., Fischer-Kowalski, M., Krausmann, E., Weisz, H., Winiwarter, V., 2004. Progress towards sustainability? What the conceptual framework of material and energy flow accounting (MEFA) can offer. Land Use Policy 21 (3), 199–213.
Haeckel, E., 1866. *Generelle Morphologie der Organismen*. Druck und Verlag von Georg Reimer, Berlin.
Haeckel, E., 1900. The Riddle of the Universe. Harper & Brothers Publishers, New York and London.
Harris, M., 1979. Cultural Materialism: The Struggle for a Science of Culture. Random House, New York.
Hayward, T., 1994. Ecological Thought. Polity Press, Cambridge.
Janssen, M.A., van den Bergh, J.C.J.M., 1999. SIMBIOSES, modelling industrial metabolism in a multi-regional economic system. Discussion paper TI-99-060/3Tinbergen Institute, Amsterdam/Rotterdam.
Janssen, M.A., van den Bergh, J.C.J.M., van Beukering, P.J.H., Hoekstra, R., 2001. Changing industrial metabolism: methods for analysis. Popul. Environ. 23 (2), 139–156.
Jonas, H., 1966. The Phenomenon of Life: Toward a Philosophical Biology. Harper & Row, New York.
Kidd, B., 1894. Social Evolution. MacMillan, London.
Kropotkin, P., 1924. Ethics: Origin and Development. George G. Harrap & Co., LTD., London.
Kurz, R., 1991. The lost honour of labor. Orig. "Die verlorene Ehre der Arbeit", Krisis p. 10.
Kurz, R., 1994. The end of politics: theses on the crisis of the regulatory system of the commodity form. Orig. "Der Ende der Politik", Krisis p. 14.
Le Play, F., 1879. Les ouvriers européens. Etudes sur le travaux, la vie domestique et la condition morale des populations ouvrières de l'Europe, vol. I. Alfred Mame, Tours.
Lilienfeld, P., 1896. La pathologie sociale. Giard & Briére, Paris.
Martinez-Alier, J., 1987. Ecological economics: energy. Environment and SocietyBasil Blackwell, Oxford.
Martinez-Alier, J., 2002. The Environmentalism of the Poor: A Study of Ecological Conflicts and Valuation. Edward Elgar, Cheltenham.
Martinez-Alier, J., 2004. Metabolic Profiles of Countries and Ecological Distribution Conflicts (25/2004 — UHE/UAB).
Marx, K., 1976. Capital, vol. I. Penguin Books Ltd, Harmondsworth (ed. orig. 1867).
Moore, J.W., 2000. Environmental crises and the metabolic rift in world-historical perspective. Organ. Environ. 13 (2), 123–157.
Moore, J.W., 2009. Ecology and the accumulation of capital. Paper Presented at Workshop, Food, Energy, Environment: Crisis of the Modern World-SystemFernand Braudel Center, Binghamton University (9–10 October).
Moore, J.W., 2011. Ecology, capital, and the nature of our times: accumulation and crisis in the capitalist world-ecology. J. World Syst. Res. 17 (1), 108–147.
Murphy, R., 1995. Sociology as if nature did not matter: an ecological critique. Br. J. Soc. 46 (4), 688–707.
Ollinaho, O.I., 2012. Institutionalization and matter. Paper presented at Metaphysical Club, Helsinki, 6th March.
Ostwald, W., 1909. Energetische Grundlagen der Kulturwissenschaft. In: Ersler, Rud (Ed.), [Energetic Foundations of a Science of Culture] (Philosophical–Sociological Library), Vol. XVI. W. Klinkhardt, Leipzig, Vienna.
Padovan, D., 1999. Social morals and ethics of nature: from Pietr Kropotkin to Murray Bookchin. Democr. Nat. 3, 485–500.
Padovan, D., 2003. The concept of social metabolism in classical sociology. Revista Theomai/Theomai J. 2, 26–40.
Padovan, D., 2008. Social capital, lifestyles and consumption patterns. In: Tukker, A., Charter, M., Vezzoli, C., Sto, E., Andersen, M.M. (Eds.), System Innovation for Sustainability. Perspectives on Radical Changes to Sustainable Consumption and Production. Greenleaf Publishing, Sheffield, pp. 271–287.

Please cite this article as: Padovan, D., Metabolic exchanges and practices of regulation: The assemblage of environment and society in early social sciences, Ecological Informatics (2014), http://dx.doi.org/10.1016/j.ecoinf.2014.02.006

ARTICLE IN PRESS

Pellizzoni, L., 2011. Governing through disorder: neoliberal environmental governance. Glob. Environ. Ch. 21, 795–803.
Pomeranz, K., 2000. The Great Divergence: Europe, China, and the Making of the Modern World Economy. Princeton University Press, Princeton, NJ.
Raumolin, J., 1984. L'homme et la destruction des ressources naturelles: la «Raubwirtschaft» au tournant du siècle. Ann. 4, 798–819.
Reckwitz, A., 2002. The status of the "material" in theories of culture: from "social structure" to "artefacts". J. Theory Soc. Behav. 32 (2), 195–217.
Redclift, M., 2009. The environment and carbon dependence. Landscapes of sustainability and materiality. Curr. Soc. 57 (3), 369–387.
Rignano, E., 1928. Sociology, its methods and laws Part one. Of methods. Am. J. Soc. 34 (3), 429–450.
Sayers, S., 2007. The concept of labor: Marx and his critics. Sci. Soc. 71 (4), 431–454.
Schäffle, A., 1896. Bau und Leben des socialen Körpers. Verlag der H. Laupp'schen Buchhandlung (first ed. 1874).
Schandl, et al., 2002. Handbook of Physical Accounting Measuring Bio-physical Dimensions of Socio-economic Activities. Federal Ministry of Agriculture and Forestry. Environment and Water Management, Wien (March).
Small, A., 1905. General Sociology. University of Chicago Press, Chicago.
Sohn-Rethel, A., 1978. Intellectual and Manual Labour. McMillan, London.
Spencer, H., 1880. First Principles. A. L. Burt Publisher, New York (first ed. 1862).
Spencer, H., 1900. The Principles of Sociology, vol. III. D. Appleton and Company (first ed. 1885).
Swyngedouw, E., 2006. Circulations and metabolisms: (hybrid) natures and (cyborg) cities. Sci. Cult. 15 (2), 105–121.
Szerszynski, B., 2010. Reading and writing the weather: climate technics and the moment of responsibility. Theory Cult. Soc. 27 (2–3), 9–30.
Ward, L.F., 1884. Mind as a social factor. Mind 9 (36), 563–573.
Weber, M., 1984. "Energetic" theories of culture, (Trans. by J. M. Mikkelsen and C. Schwartz). Mid. Am. Rev. Soc. 9 (2), 33–58 (orig. ed. 1909).
Williams, R., 1980. Problems in Materialism and Culture: Selected Essays. Verso, London.
Wolman, A., 1965. The Metabolism of Cities. In: AA. VV. Cities (Ed.), Alfred A. Knopf, New York.
Worms, R., 1896. Organisme et société. Giard & Brière, Paris.
Worms, R., 1907. Philosophie des sciences sociales, vol. III. Giard et Brière, Paris.
York, R., Rosa, E., Dietz, T., 2003. Footprints on the Earth: the environmental consequences of modernity. Am. Soc. Rev. 68 (2), 279–300.

Please cite this article as: Padovan, D., Metabolic exchanges and practices of regulation: The assemblage of environment and society in early social sciences, Ecological Informatics (2014), http://dx.doi.org/10.1016/j.ecoinf.2014.02.006