Energy Systems in Material Agent Societies

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Abstract. *This paper concerns material agent societies, that is, agent societies inhabited by material agents. The paper introduces the concept of energy system of a material agent society, as the organizational sub-systems responsible for the coordination of the production, distribution and consumption of energy in material agent societies. Two models (labor-based and work-based) for energy systems are formally defined, and the conditions of their equilibrated functioning formulated. The possible relation between economic and political systems, and energy systems, in material agent societies, is briefly indicated.*

Resumo. *Este artigo concerne sociedades de agentes materiais, quer dizer, sociedades de agentes habitadas por agentes materiais. O artigo introduz o conceito de sistema de energia de uma sociedade de agentes materiais, como o sub-sistema organizational responsável pela coordenação da produção, distribuição e consumo de energia em sociedades de agentes materiais. Dois modelos (baseado em labor e baseado em trabalho) de sistemas de energia são formalmente definidos, e as condições de seu funcionamento equilibrado são formuladas. A possível relação entre sistemas econômico e político, e sistemas de energia, em sociedades de agentes materiais, é brevemente indicada.*

1. Introduction

The issue of *energetical self-sufficiency* of general agent systems has been a current issue, for some time now, concerning systems like *robots* and other types of *mobile* systems (see, e.g., [MacFarland and Spier 1997]) .

Regarding specifically the agents of Multiagent Systems, it seems that the issue has not aroused, mainly because the area has concentrated its efforts on *software* agents, which gather the energy necessary for their operation from the underlying computing system.

As *agents* are, in fact, essentially abstractions of robots (see the way concept of *agent* is presented in, e.g., [Russel and Norvig 2009]), one should expect that at some point in time the two areas of Robotics and Multiagent Systems will come closer than they are, at the moment, and the social mechanisms investigated in the area of Multiagent Systems will be instantiated in appropriate ways in terms of *societies of autonomous robots*.

The latter is the subject of our concern, in this paper. For that, we take the term *material agent society* to mean an agent society whose agents are endowed with material bodies. Having material bodies, agents need energy for their operation, and are in need of *laboring* for gathering the energy they need from their environment, and for producing packs of energy (*energy objects*) that can be distributed among the society.

We claim that the *energy production and distribution processes* that the agents may possibly realize in material agent societies can best be understood in terms of *energy systems* constituted in those societies. The paper formally introduces, thus, some of the concepts that are needed for the design and analysis of the structure and functioning of the energy systems of material agent societies.

Section 2 discusses the basic terms (energy, labor, work) with which the concept of *energy system* can be defined.

Section 3 reviews the concept of *agent society*, with a focus on the particular case of *material* agent societies.

Section 4 is the main section of the paper, where the concept of *energy system of material agent society* is formally defined.

Section 5 analyzes two base types of energy systems of material agent societies, namely, the *labor-based* and the *work-based* energy systems.

Section 6 discusses some related works and brings the Conclusion.

2. Labor, Work, Action, and Energy

The starting point of this work is Hanna Arendt's characterization of the three types of central activities of *active life*, namely, *labor*, *work*, and *action* [Arendt 1958], which we summarize as follows:

- *labor* is the set of activities related to the *immediate physical maintenance* of the structure and operation of the bodies of the individuals of a given species;
- *work* is the set of activities related to the *production of objects* that, being capable of persisting beyond the individuals lives, constitute a system of objects that support the structure and operation of the collective of the individuals of that species;
- *action* is the set of activities that the individuals exercise directly on each other, in order to drive the system of their individual and collective lives.

We claim that this conceptualization determines a path toward a proper understanding of the notion of *material agent society*. For that, we take the *need of physical energy* as the main concern of the individuals and their collectives, and the central issue around which proceed the three types of activities of their active life.

In this paper, however, we restrict ourselves just to the analysis of the relations that exist, in material agent societies, between the *need of physical energy* and the sets of *labor* and *work* activities. We leave for further investigation the analysis of the relation between the need of physical energy and the set of *action* activities.

3. Material Agents and Material Agent Societies

A *material agent* is an agent with a physical body. The having of a physical body implies that every material agent requires *energy* to operate (that is, to perform its *behaviors* and *interactions*, and to *function properly* in the society that it inhabits).

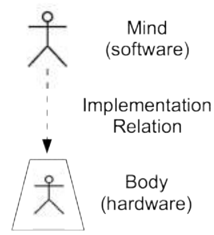

Figure 1. The mind-body architecture of a material agent.

In consequence, *material agent societies* can exist as operational systems only if situated in a *material environment*, from which their material agents can extract the energy they need for their operation.

We call *ground* the part of the material environment that material agents can operate on to extract the energy they need.

We say that a material agent is *self-sufficient*, from the energetic point of view, if it can get by itself, from the available ground, the energy it needs for its operation. Otherwise the material agent is said to be *dependent* on other material agents, from the energetic point of view.

We assume that material agents are so constituted that a *drive for energy seeking* can arise in material agents, and some *energy seeking behavior* can be activated in them, in response to that drive, when the *need of energy* goes beyond some specified threshold (see [Costa and Dimuro 2014] for the notion of *drive* in artificial agents).

In consequence, we assume that *rationally determined behaviors*, of seeking and storing energy in advance of surgings of energy needs, can occur in material agents.

3.1. The Energetical Characterization of Material Agents

We assume that material agents are organized in terms of a mind-body articulation, with the body constituted by an energy-consuming material mechanism whose operation is regulated by the software-based mind. Mind and body are interconnected through an implemenation relation (see Fig. 1).

To formally characterize material agents from the energetical point of view, we assume the following:

- time, denoted by $T = t_0, t_1, ...$, is taken to be discrete, and that there is a definite *time unit* separating any two time instants, which we denote by: tu;
- there is a *quantitative notion of energy*, discretely quantified, which we denote by $E = e_0, e_1, ...$, so that there is a definite notion of *energy unit*, a *quantum* that we denote by: eu;
- the operation of each material agent mag determines, at each time t, a definite *operation cycle*, during which the agent *consumes* a definite amount of energy units, which we denote by: $ec^t_{mag} = c \;\; eu/cycle$;
- at each time t, each material agent mag operates under a definite *operation speed*, that is, it performs a certain number of operation cycles per time unit, which we denote by: $speed^t_{mag} = s \;\; cycles/tu$;

- in consequence, for each material agent mag, at each time t, one can determine its *instantaneous energy consumption*, at that time, given by: $iec_{mag}^t = speed_{mag}^t \times ec_{mag}^t$.

We require that every material agent mag be endowed with an *internal stock of energy* (ise_{mag}^t) that, at each time t, determines the amount of energy the agent has internally available, to support its operation.

In addition, we require that each material agent be endowed with two threshold levels. One of the thresholds, called *critical energy threshold*, denoted by cet_{mag}, determines the level of stocked internal energy below which energy seeking behaviors are to be activated in the agent. That is, energy seeking behaviors are to be activated in mag at any time t at which $ise_{mag}^t - cet_{mag} < 0$.

The other threshold, called *minimal energy threshold* denoted by met_{mag} determines the level of stocked internal energy below which the agent mag is incapable of any type of operation, having to rest quiet until some external agent feeds it with the minimum required energy. That is, the material agent mag stops all its operations at any time t at which $ise_{mag}^t - met_{mag} < 0$.

Also, we assume that:

- every material agent mag is capable of performing, in the ground of the material agent society, an *energy digging* operation, with which the agent digs a definite amount of *dug energy* at each performance of the operation, which we denote by $de_{mag} = e \;\; eu/dig$;
- every material agent mag, at each time t, performs the energy digging operation at a definite *digging rate*, which we denote by: $dr_{mag}^t = d \;\; digs/tu$;
- we call *instantaneous energy yield* the amount of energy that a given material agent mag digs, at a time t, from the ground on which it operates, and we denote such yield by $iey_{mag}^t = dr_{mag}^t \times de_{mag} \;\; eu/tu$.
- we call *instantaneous energy excess* produced by a material agent mag, at the time t, denoted by iee_{mag}^t, the *difference* that occurs, at the time t, between the instantaneous energy yield iey_{mag}^t and the instantaneous energy consumption iec_{mag}^t of the agent mag, at the time t. That is: $iee_{mag}^t = iey_{mag}^t - iec_{mag}^t$;
- and we assume that, at each time t, the instantaneous energy excess iee_{mag}^t is *transferred* to the instantaneous stock of energy ise_{mag}^t, so that, $ise_{mag}^{t+1} = ise_{mag}^t + iee_{mag}^t$. But, notice that iee^t may be positive, negative, or null.

In many situations, we will be mainly interested in the *net energy excess* that a material agent mag produces along a given *time interval*. For the time interval $\Delta t = t' - t$, this is given by the summation: $nee_{mag}^{\Delta t} = \sum_{\tau=t}^{\tau=t'} iee_{mag}^{\tau}$.

In particular, we will be interested in situations where the net energy excess $nee_{mag}^{\Delta t}$ obtained by the energetically self-sufficient material agent mag during a time interval $\Delta t = t' - t$ is positive enough not only to take its instantaneous stock of energy $ise_{mag}^{t'}$ above the critical energy threshold cet_{mag}, but also to allow for energy to be *supplied* to other material agents through the intervention of the *energy system* of the agent society (see Sect. 4).

3.2. Material Agent Societies

Figure 2 illustrates, with a simple example, the architecture of material agent societies.

At the lowest architectural level is the material environment ($MEnv$) of the society, containing the material objects that participate in the behaviors and interactions of the components of the society.

Next, in the hierarchy of architectural levels, is the populational structure (Pop), constituted by the material agents of the society.

Notice the double situation: the material agents, considered as complete agents (minds and bodies), belong to the populational structure while their bodies, considered as material objects, belong to the material environment.

The micro-organizational level (Org_ω) is constituted by the *organizational roles* that the agents perform in the organizations of the society. Such organizations belong to the meso-organizational structure (Org_μ) and are constituted by networks of interacting organizational roles (possibly organized in terms of sub-organizations, which also belong to Org_μ).

Sets of organizations of the society may network with each other, in *inter-organizational networks* that constitute the *organizational sub-systems* of the society, which belong the macro-organizational structure (Org_Ω).

The figure indicates by dotted trapezoids two organizational sub-systems, showing the organizations that constitute them and the organizational roles that constitute such organizations. The implementation relation show which components implement each organization unit or organization, and also which material agents implement each organizational role (some organizational roles are implemented by more than one agent).

Notice that Org_ω, Org_μ and Org_Ω constitute the overall organizational structure (Org) of the material agent society.

At the right side of the model is the symbolic environment ($SEnv$) of the society, containing the symbolic objects that participate in the behaviors and interactions of the components of the society (symbolic objects that have a material substrate combine a symbolic component with a material component, with the latter implementing the former, much as a material agent combines a mind with a material body that implements it).

Notice that both $MEnv$ and $SEnv$ are considered to be *internal environments* of the material agent society. Not shown in Fig. 2 is the *external environment* of the society (for instance, the other agent societies with which it interacts [Costa 2017]).

Interactions of components situated at higher levels are implemented by interactions between components situated at lower ones, much as higher level components are implemented by lower level ones (but we omit the representation of the implementation relation for interactions in the figure).

In the same way that the minds of the agents regulate the operation of their bodies, the minds of the agents regulate the behaviors and interactions of the organizational roles that they perform, as well as the behaviors and interactions of organizations and organizational sub-systems that those organizational roles implement[1].

[1] As has already become usual in the multiagent systems area, we may construe the implementation relations between such behaviors and interactions in terms of the *counts-as* relations that were introduced by John Searle [Searle 1995].

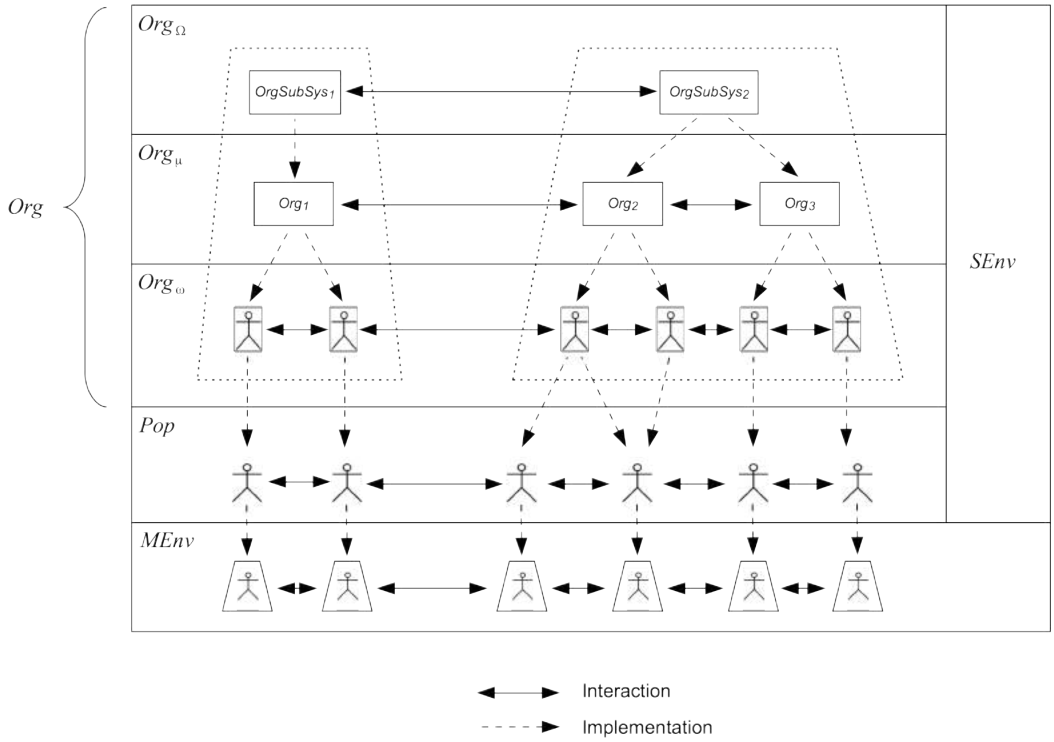

Figure 2. Example architecture of a material agent society.

4. Energy Systems of Material Agent Societies

Of the various types of *organizational sub-systems* that can be formed in material agent societies, we are interested in this paper in a particular type, namely, the organizational sub-systems that may be called the *energy systems* of those societies.

We give, here, a *functional* characterization of such energy systems. And we argue that every material agent society that is heterogeneous regarding the energetical self-sufficiency of their material agents (mixing self-sufficient and non self-sufficient agents) and *energetically closed* regarding its interaction with the external environment (so that it cannot be supplied externally with the needed energy), has to be endowed with an organizational sub-system that functions as its *energy system*.

We let for the next section the *architectural characterization* of the energy systems of material agent societies.

4.1. The Functional Characterization of the Energy Systems of Material Agent Societies

We call *interactional function* of a component of an agent society [Costa and Dimuro 2010] a *pair of exchange processes* that the component performs with another component of the society, so that those exchanges contribute in the support of the proper functioning of that other component.

By the *functional characterization* of an organizational sub-system of an agent society we understand, thus, the determination of the *set of interactional functions* which

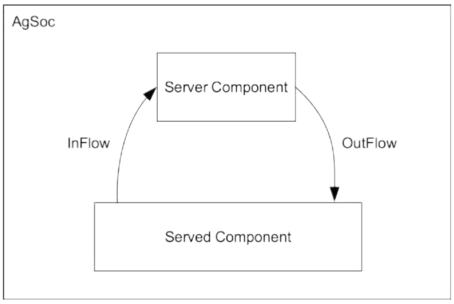

Figure 3. The *server* and *served* components of a generic interactional function in an agent society.

that sub-system performs in the society.

4.1.1. Functional Characterization of Generic System Components

In general, an interactional function of a component of an agent society may be pictured as in Fig. 3. Formally, we state such interactional function as follows.

Let C_1 and C_2 be components of an agent society. Let B_2 be a behavior that C_2 is required to perform in that society. If it happens that, in the context of that agent society, C_2 can perform B_2 only if an exchange process ep happens between C_1 and C_2, and ep can happen between C_1 and C_2 only if C_1 and C_2 respectively perform the behaviors B_1 and B_2, then we say that C_1 performs an interactional function for C_2, and we denote such interactional function by the expression $\langle C_1 : B_1 \rangle \overset{ep}{\dashrightarrow} \langle C_2 : B_2 \rangle$.

In such situation, we say that C_2 is the component *served* by the interactional function performed by the *server component* C_1 (see Fig. 3 where the *inflow* and the *outflow* between the server and the served components denote the *exchange process* between such components)[2].

4.1.2. Functional Characterization of Energy Systems of Material Agent Societies

The basic form of energy systems of material agent societies determines that three main activities are involved in their functioning: *production*, *distribution* and *consumption* of energy objects.

Production and *consumption* of energy objects are the two *core activities* of a material agent society endowed with energy systems, *production* being the core activity of the energy system, *consumption* being the core activity of the other components of the agent society. *Distribution* is the intermediary activity, that the energy system and its consumers jointly perform, to allow the energy objects produced by the former to be distributed to its various consumers.

We formulate such basic *functional scheme* of the energy system of a material

[2]But notice that functional schemes are *symmetrical*, so that a function $\langle C_2 : B_2 \rangle \overset{ep}{\dashrightarrow} \langle C_1 : B_1 \rangle$ is also performed, so that C_2 operates as a server for C_1, with reversed directions in their inflow and outflow [Costa and Dimuro 2010].

agent society as follows:

$$\langle \mathit{Producers} : \mathit{Production} \rangle \overset{\mathit{Distr}}{\dashrightarrow} \langle \mathit{Consumers} : \mathit{Consumption} \rangle$$

There are two main general situations in which such functional scheme may be, depending on what one takes as the constancy of the production activity of the producers:

- either all of the *Producers* are always energetically self-sufficient;
- or some of the producers are not always energetically self-sufficient and should be sometimes supplied of energy by other producers.

For simplicity, we consider that all the *Producers* are always energetically self-sufficient, so that the amount of energy made available by the *Production* process has already been deduced of the energy that the *Producers* needed for their own operation and is, thus, the exact amount of energy that can be distributed to the *Consumers*.

Also for simplicity, we consider that there is no loss of energy during the energy distribution process, and we consider that, at each time t, all the energy that is distributed to the *Consumers* is completely consumed or stocked by them, without loss.

4.1.3. The Functional Indispensability of Energy Systems in Material Agent Societies

The *functional indispensability* of an energy system in a material agent society arises when not all *material agents* are allowed to, or interested in, acting as *energy producers*, in that society.

For, in such case, the energy producers should be charged with producing energy not only for themselves, but also for the consumers that do not produce their own energy, and the energy system becomes necessary as a means for coordinating the production, distribution and consumption of energy among all the members of the society.

The only condition in which an energy system is not indispensable in a material agent society where not all energy consumers act as energy producers is that in which agents that are *external* to the society operate so as to provide the necessary complimentary energy.

In this paper, however, we are interested in material agent societies that are *energetically closed*, regarding their production, distribution and consumption of energy, that is, material agent societies where the intervention of external agents to provide and distribute energy to the members of the society is of minimal or null relevance.

The condition of *energy closure* of the agent society is, thus, what imposes the indispensability of energy systems, in those agent societies. And the *energy system*, in such situations, is the functional component that endows the material agent societies with the condition of *energetic autonomy* regarding its external environment.

Remark, however, that the condition energetic autonomy can be sustained by a material agent society only if the energetically self-sufficient material agents that participate in that society are capable of digging at least all the energy they need for their own operation, plus the energy necessary for sustaining the operation of all the material agents that are not energetically self-sufficient.

5. Two Architectural Types of the Energy Systems for Material Agent Societies

We build on [Arendt 1958] to define the two architectural types of energy systems that we consider in the present section: the *labor-based energy systems* and the *work-based energy systems*.

5.1. Labor-Based Energy Systems

We call *labor* the set of activities, by one or more material agents, through which *energy is extracted* from the available ground, and immediately made available for consumption, in a material agent society.

We call *labor-based energy system* any energy system whose activity is essentially based on *labor* activities (that is, is not essentially based on external energy supplies).

Given that *labor* is the production and distribution of energy for immediate consumption in a material agent society, the fundamental operational requirement of labor-based energy systems is that of supporting the fast distribution of energy, for that immediate consumption.

The kernel of labor-based energy systems has to be, thus, a *network of distribution channels* capable of realizing such fast distribution of energy.

Formally, then, we characterize the architecture of labor-based energy systems as a structure $LBES = (Producers, Consumers, Channels)$ where:

- $Producers$ is a non-empty set of *producers*;
- $Consumers$ is a (possibly empty) set of *consumers*;
- $Channels \subseteq Producers \times Consumers$ is a *distribution relation*, such that for each pair $(prod, cons) \in Channels$ we say that there is a *distribution channel* between the producer $prod$ and the consumer $cons$;
- and such that each consumer is supplied with energy by at least one producer, that is, for each consumer $cons \in Consumers$ there is at least one producer $prod \in Producers$ such that $(prod, cons) \in Channels$.

Given our assumption, mentioned above, of *no loss of energy* in the consumption processes, we may formulate the following equations, stating the *equilibrium conditions* under which a labor-based energy system operates.

Remark that, in any labor-based energy system, at each time, the total amount of energy consumed by any consumer $cons$ equals the total amount of energy that was supplied to it, which equals the total amount of energy that the producers that are connected to it delivered through their respective distribution channels.

That is, let $Producers_{cons} = \{prod \mid (prod, cons) \in Channels)\}$ be the set of producers that supply energy for the consumer $cons$. Let $\sup[(prod, cons)]^t$ denote the amount of energy supplied by $prod$ to $cons$, at the time t. Then, the relation between the instantaneous energy consumed by $cons$ at the time t (denoted by iec^t_{cons}) and the total amount of energy supplied to $cons$ at that time is given by:

$$iec^t_{cons} = \sum\{\sup[(prod, cons)]^t \mid prod \in Producers_{cons}]\}$$

Also, given our additional assumption of *no loss of energy* in the distribution process, we remark that, in any labor-based energy system, at each time, the total amount of energy distributed to the consumers is exactly the amount of energy that the producers have produced in excess of their own energy needs.

That is, let $Consumers_{prod} = \{cons \mid (prod, cons) \in Channels\}$ be the set of consumers that are supplied with energy by the producer $prod$. Then, the relation between the total amount of energy supplied by $prod$ to its consumers and the instantaneous energy excess produced by $prod$, at each time t (denoted by iee^t_{prod}), is given by:

$$\sum\{\sup[(prod, cons)]^t \mid cons \in Consumers_{prod}\} = iee^t_{prod}$$

Thus, instantaneity is the main *operational* requirement of the labor-based energy systems, and the availability of a network of energy distribution channels, to provide such instantaneous energy distribution, is their main *architectural* feature.

5.2. Work-Based Energy Systems

We call *work* the set of activities, by one or more material agents, through which *energy is embedded in objects*, after being extracted from the available ground, in a material agent society.

We call *work-based energy system* any energy system whose activity is essentially of the *work* type.

Having been injected into *energy objects*, energy may be *stored* in appropriate storages, and also *exchanged* between material agents, through exchange processes operating on such storages.

Given that *work* is the production of energy objects, the distribution and consumption of energy in the society is not performed, in general, immediately after its production, but is differed in time, on the basis of the storage and exchange of those energy objects.

The fundamental architectural feature of work-based energy systems is, then, that it supports the distribution and consumption of energy on the basis of the storage and exchange of *energy objects*.

The kernel of the architecture of work-based energy systems has to be, thus, a *network of stores* for the distribution of energy objects, with such stores supporting operations of *delivery* and *retrieval* of energy objects.

Let $EnergObj$ be the set of all energy objects that may be stored in the stores of the work-based energy systems of a material agent society. Formally, we may characterize the architecture of the work-based energy system of that material agent society as a structure $WBES = (Producers, Consumers, Stores, OutLinks, InLinks, States, deliver, retrieve)$ where:

- $Producers$ is a non-empty set of *producers*;
- $Consumers$ is a (possibly empty) set of *consumers*;
- $Stores$ is a set of *stores* for energy objects;
- $States = Stores \times T \to \wp(EnergObj)$ is the set of *states* in which the energy system may be, each $state \in States$ giving, at the time $t \in T$, and for each

store $sto \in Stores$, the set $state(sto, t) \in \wp(EnergObj)$ of energy objects that are stored in that store, at that time [3]; we often denote $state(sto, t)$ by sto^t;

- $OutLinks \subseteq Producers \times Stores$ is the *out link relation* which determines, for each *producer* which *stores* it may use to store energy objects, after having produced them;
- $InLinks \subseteq Stores \times Consumers$ is the *in link relation* which determines, for each *consumer* which *stores* it may use to retrieve energy objects, in order to consume the energy embedded in them;
- $deliver_{sto} : \mathbf{EnergObj} \times States \to States$ is the operation of *delivery* of energy object that a producer $prod$ may perform on the store sto (if the producer can use that store, i.e., if $(prod, sto) \in OutLinks$); if the delivery operation is performed at the time $t \in T$, with an energy object $eobj \in EnergObj$, then it holds that:

$$deliver_{sto}(eobj, sto^t) = sto^{t+1}$$

  where $sto^{t+1} = sto^t \cup \{eobj\}$;
- $retrieve_{sto} : States \to EnergObj \times States$ is the operation of *retrieval* of an energy object that a consumer $cons$ may perform on a non-empty store sto which it may use (i.e., $sto, cons) \in InLinks$); if the retrieval operation is performed at the time t, then it holds that:

$$retrieve(sto^t) = (eobj, sto^{t+1})$$

  where $sto^{t+1} = sto^t - \{eobj\}$, where $eobj$ is the object retrieved by the operation.

The *equilibrium condition* of work-based energy systems, operating under the condition of non-loss of energy, expresses the fact that the total amount of net energy excess (nee_{prod}) delivered by each producer $prod$, during a certain time interval, should equal the sum of the following amounts:

- the net amount of energy stored in the stores of the material agent society during that time interval (that is, the difference between the total amount of energy delivered to those stores and the total amount of energy retrieved by the consumers, during that time interval);
- the net sum of energy stocked by the consumers during that interval;
- the energy that was consumed by the consumers, during that interval.

Let $\mathrm{kept}[S]^t$ denote the net amount of energy units that was *kept* in the store S, at the time t, that is, the difference between the amount of energy delivered to X, and the amount of energy retrieved from that store, at that time. The *equilibrium condition* for a work-based energy system, regarding a time interval $\Delta t = t' - t$, may be stated as:

$$\begin{aligned}\textstyle\sum\{nee^{\Delta t}_{prod} \mid prod \in Producers\} = \\ \textstyle\sum_{\tau=t}^{\tau=t'}\{\mathrm{kept}[sto]^\tau \mid sto \in Stores\} \\ +\textstyle\sum_{\tau=t}^{\tau=t'}\{\mathrm{kept}[ise_{cons}]^\tau \mid cons \in Consumers\} \\ +\textstyle\sum_{\tau=t}^{\tau=t'}\{iec^{\tau}_{cons} \mid cons \in Consumers\}\end{aligned}$$

[3] For every set X, we denote by $\wp(X)$ the power-set of X.

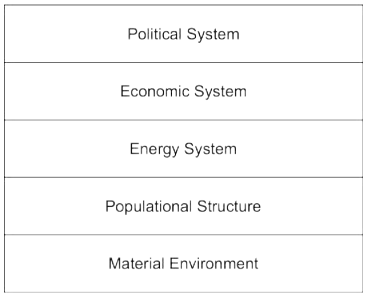

Figure 4. The energy, economic and political systems of material agent societies.

6. Related Work and Conclusion

This paper aimed to contribute to the proper theoretical treatment of the energetical aspects of material agent societies. For that, the paper introduced the idea of *energy systems* of material agent societies, and formal concepts for the analysis of their structure and functioning.

The background of the paper is a *materialistic* approach to agent societies, where *energy* is taken to be the central concern. The overall approach was built on Hanna Arendt's analysis of the *active life* in human society, given in terms of the activities of *labor*, *work* and *action* [Arendt 1958].

The concept of energy system of material agent society was then defined in a way that should support the definition of two additional (and indispensable) organizational sub-systems of energetically autonomous material agent societies, namely, the *economical* and the *political* organizational sub-systems, through which the structure and functioning of the energy systems of those societies are to be managed (see Fig. 4).

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