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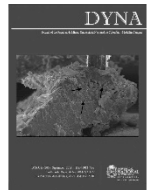

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Entropy and negentropy of private electric vehicles in urban systems: homeostasis of mobility in Mexico

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Abstract
Since many years ago, private electric vehicles threaten to interact massively and substitute a large proportion of internal combustion vehicles; nevertheless, the homeostasis of the speed and the elapsed time in domestic journeys fluctuate between the phases critical and sub-critical due to the entropy of the production and consumption processes that pressure urban mobility subsystems and vice versa. This work considers from the *Systems Theory* the interaction of the entropic components of Mexican urban mobility through the model entropy-homeostasis-negentropy, which is an adaptation of the model pressure-status-response, issued by the Organization for Economic Cooperation and Development with the intention of showing qualitatively which is the most probable scenario of the private electric vehicle for urban mobility. The results show that a larger number of vehicles produce a higher intra-systemic entropy. Thus, it is essential to implement definitive negentropies to favour electric mobility.

Keywords: entropy; homeostasis; urban mobility; negentropy; private electric vehicles.

Entropía y negentropía del vehículo eléctrico particular en sistemas urbanos: homeostasis de la movilidad en México

Resumen
Hace años que el vehículo eléctrico de uso particular amenaza con interactuar masivamente y sustituir buena parte de la carga vehicular de combustión interna; sin embargo, actualmente la homeostasis de la movilidad urbana relacionada con la velocidad y el tiempo en los trayectos motorizados cotidianos transitan entre las fases sub-crítica y crítica, por la entropía de los procesos de producción y consumo que presionan a este subsistema y viceversa. Este trabajo analiza desde la teoría de los sistemas la participación de los componentes entrópicos de la movilidad urbana en México, a través del modelo entropía-homeostasis-negentropía; una adecuación del modelo presión-estado-respuesta de la Organización para la Cooperación y el Desarrollo Económico, con el objetivo de mostrar cualitativamente el escenario más probable en la interacción vehículo eléctrico particular-movilidad urbana. Los resultados indican que un mayor número de unidades vehiculares generan mayor entropía intra-sistémica. En este sentido, es indispensable implementar negentropías definitivas para la automovilidad eléctrica.

Palabras clave: entropía; homeostasis; movilidad urbana; negentropía; vehículo eléctrico particular.

1. Introduction

The work done by Sadi Carnot and Rudolf Clausius enable the formulation of the second principle of thermodynamics: "*in a closed system, a certain quantity, called entropy, must increase to a maximum, and eventually the process comes to a stop at a state of equilibrium*" [1]. At first, entropy was defined in terms of thermodynamics; however, after the arrival of mechanical statistics this concept has been defined from the notions of probability proposed by Ludwig Boltzmann [2]. Latter, "*in 1948, by analogy with the Boltzmann probability expression of the classical concept of entropy, Shannon introduced the abstract entropy as a way to measure information or uncertainties from arbitrary probable experiments*" [3].

As time goes by, in isolated systems entropy tends to increase, which is a natural and irreversible feature of the

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physical universe both for living and inanimate things. However, it has been explained that technology may decrease, at least to a certain degree, the natural growing of entropy in open systems, and that might happen through restrictions applied in the environment [4,5]. In other words, the developments in this field might contribute to minimize the entropy originated by the anthropic performance, through contrary entropic actions; which are also defined as negative entropies, negentropies, and sintropies.

According to Shannon in the context of *Information Theory*, the aforementioned entropy can be used to reduce the entropy of the system [6], or as stated by Wiener [7, 8] the information would become a measure of order, especially in living beings; therefore, *"entropy is ameasure of the lack of detailed information about a physical system. The greater is the information, the smaller will be the entropy"* [9]. In this way, what Shannon understands as entropy, other authors define it as negentropy [7-10]; in summary, Shannon and Weaver define information as *"(…) an expression isomorphic to negative entropy of thermodynamics"* [1].

At present, it is possible to find the expression entropy linked to a number of concepts and categories of concepts associated with energy availability but not used in connection with labour production, disorder, instability, intra systemic disorder, heat, irreversibility, wear, deterioration, chaos, uncertainty, lack of information, ignorance, among other expressions [2,3,9-18]. Nonetheless, in the urban context it has become highly complex to associate the concept due to the degree of abstraction and the difficulty to determine isomorphisms in the structure of the boundary and the behaviour of the elements of the urban system.

On one hand, it is presumed the existence of an internal systemic concatenation configuring urban morphology through positive and negative interactions, and on the other hand, there may be functional problems occurring in one of the system´s elements and that might alter homeostasis in one or more of its different phases; however, there is consensus respecting the following conclusión *"the city is a system that causes deterioration, and in some way order depends on such deterioration, which it is the basis for its structure and functioning"* [16].

Urban systems depending on auto-mobility experience some functional problems related to:

a) *financial cost,* due to the continual investment on paved surfaces, huge investments in concrete constructions, investment and maintenance in signalling and traffic lights, financial availability to deal with sanctioning issues due to high speed and other related matters, measuring alcohol level systems, preventive or corrective maintenance liabilities, fuel expenses, vehicle taxes, registration certificates, emissions certificates, car insurance for own and third parties damage protection.
b) *Social expenses* due to imbalance in the formula vehicle-user-road, increase in the likelihood of accidents with physical and emotional temporary or permanent implications, down time due to traffic congestion, physical or mental damages caused by gas emissions, noise, stress.
c) *environmental impact* due to alterations in land topography, induced vibrations, changes in vegetal cover, pollution emissions, infiltration of oils to drainage systems, pollution of superficial and groundwater systems, among other negative conditions.

In contrast with the aforementioned expenses, there are some benefits associated with the quality of the journey (comfort) as follows: availability, flexibility, freedom and the minimization of the time factor in the periurban journeys, as time has become a very limited resource for people. In this way, intervention in the motorway physical urban area intends to take the maximum advantage of time at commuting that is to say *"spending less time in mobility affairs, because the most quantity of time invested in mobility implies greater economic or social cost"* [10].

Indeed, vehicles have become a type of catalyser to access different locations in the city and outside, and their ample availability has produced an increase in entropy *"(…) pushing the global order of the urban system forward and nobody knows how or when it will end"* [16]. In summary, auto-mobility is a trend that unsettles the system and its subsystems mainly due to the pressure from extra systemic components (matter and energy) and due to the limitations and the dimensions of the roadways infrastructure able to contain a maximum load of intra systemic vehicle circulation; then it is not completely accurate to suppose as constant the inter nodal geometric distance (*d*) and the restrictions in the maximum speed limit settled by intra urban law (*v*), therefore, indiscriminate introduction of new vehicles into the roads system, implies the generation of entropies linked with time increase (*t*) according the following equation:

$$t = \frac{\mathrm{d}}{\mathrm{v}} \tag{1}$$

On this basis, the quantity and the capacity of the roadways infrastructure becomes unable to keep up with a limitless increase of vehicle usage. Overcrowding at certain times decreases speed and therefore travelling time increases. *"The geographic distance or Euclidean distance does not change at all. Notwithstanding, time, may vary in terms of speed and position respectively"* [10]. Therefore, with the aim of showing the most probable scenario of interaction of electric vehicles particularly in urban mobility, the research poses the following questions: What are the possible scenarios in connection with speed and time in Mexico City?, and Is there any contribution from private electric vehicles to the issue of speed and time?

2. The city in the prospection of the *systems theory*

This theory was introduced no longer than a century ago, however, its principles have permeated different fields of scientific research. At the same time, there have been a number of methodologies and models based in the considerations of Bertalanfffy´s theory. Respecting the planning and behaviour of the city the systemic approach has been pretending to be incorporated since many years ago [19-27]. Therefore, this works assumes that the city represents to the pressured and pressing system, in other words, the city, hereinafter *the urban* is identified as the open urban system

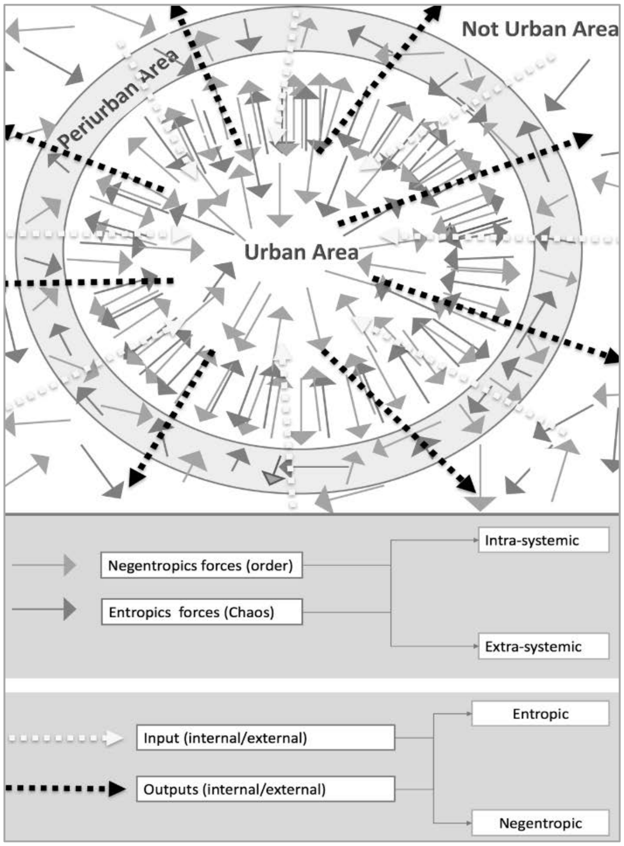

Figure 1. Entropic and negentropic forces in the *urban system* and supporting systems (not urban area).
Source: The author.

and what it occurs there does not belong to the urban system which is identified as no urban, or the environment that does not contribute to the urban pressure system. At the same time, in the boundary between the *urban* and *not urban* it will be found what is known by many as *periurban*.

Consequently, the triad *system-boundary-environment*, or *urban-periurban-not urban* entails intentional and unintentional forces affecting the morphology of the system and its subsystems. That morphology of the system becomes an hybrid, which is a complex combination depending of the *in situ* performance of the entropy and negentropy struggle (Fig. 1).

Periurban areas never have a static position, their location is not permanent, they are continually subject to movements to the no urban areas and not on the contrary. The *urban system* and its components *"press the supporting systems by the extraction of raw materials with the intention of increasing organization or complexity"* [28].

In mobility affairs and in certain circumstances private vehicles solve some problems associated with time when commuting from peri-urban to urban areas or vice-versa. Under these conditions the force temporarily counteracts the entropy caused by the geometric prolongation of the disperse housing model. Nevertheless, if private vehicles reduce entropy in the urban-not urban interphase, some conditions such as: a) absence or inefficacy of alternative options to private vehicles, b) poor physical infrastructure, and c) insecurity that threatens physical integrity from t_0 to t_1, from t_1 to t_2 and from t_2 to t_3, where:

t_0 = represents the place of origin of each user.
t_1 = represents the time where the user enters to an alternative means of transport.
(t_1, t_2) = represents the elapsed time in transport.
t_3 = represents the place of interest where the user must go; it also represents the place where the user left the transport means up to his final destination.

Indeed, it is necessary to consider the travel time from t_0 up to t_1, and the waiting time in t_1. In this way a private vehicle becomes a limited negentropy with positive temporary effects, which is conditioned by the relationship cost-benefit where not using a private vehicle results in larger financial and social costs in contrast with not using it; however, at getting near to *the urban*, the private vehicle does not solve the time concern, but it becomes an environmental entropic component, as well as a financial and social problem.

3. Materials and methods: from the Pressure-State-Response (PSR) model to the Entropy-Homeostasis-Negentropy (EHN) model

The model PSR *"(…) allows the establishment and redirection of public policies and the criteria required for decision making in main State sectors (...)"* [29]; that occurs by the provision of a conceptual-theoretical framework working through environmental indicators which measure and report the state of the environment [30].

On the other hand, the model EHN classifies qualitatively each phase of the exerted pressure, the existing conditions of the open system and the undertaken responses to reduce entropy caused by pressure forces. In this way, vehicles are understood as a casual force of entropy in the urban system, and it they become an intra systemic component that make pressure upon the other elements in urban and not urban systems; and a pressure for itself as a subsystem. Therefore, entropy can be identified in three phases: subcritical, critical and hypercritical. Homeostasis of the process of urban mobility as an intra systemic and inter systemic product can be: reversible, quasi reversible or irreversible, and the implemented negentropy as: non-existing, occasional, or definitive (Fig. 2).

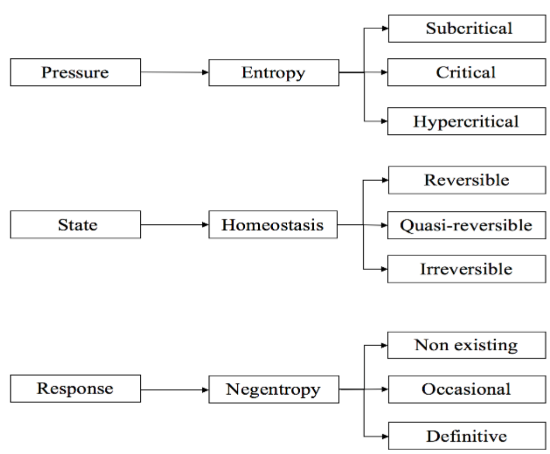

Figure 2. Subclassifications of the EHN Model.
Source: The author.

Entropy in its subcritical phase does not inhibit the functioning of the system; in other words, the system works even when abnormalities occur in internal processes that may affect operability, or due to the interventions of external forces. In such a case, the systems homeostasis is not severely affected, and therefore, it can revert entropies or buffer impacts preventing significant residual damages due to the intrinsic contention of dissipation structures able to regulate processes, or it may produce own or induced negentropies that contribute to the configuration of adaptive states for the development of emerging subsystems. On the other hand, in systems with a critical phase of entropy it is urgent a negentropic intervention; in that case, the system homeostasis has been affected with a resulting malfunctioning of the system. Even more, some elements and processes hardly ever are able to reverse the entropic affectations or reach adaptative states. Then, the prospective scenario is uncertain, because while some components are not able to recover their original shape, others, in contrast may become hybrid and may adapt and work according new conditions. Finally, for systems with an entropy in a hypercritical phase the structure of the system will not be able to recover its previous state, and the outworking in terms of time effectiveness has exceeded both its components and environment severely.

In this context, and according to the EHN Model, it is possible to minimize the different levels of entropy in each of the three phases of system homeostasis up to get even instances of stable conditions. In such a way non existing negentropy does not consider any intervention to reduce the levels of entropy; the system worsens its homeostasis by itself and increases the entropy as time goes by. In this case negative entropy is null. On the other hand, some *in situ* strategies to reduce the levels of entropy derived from abnormalities in one element that does not take into account the relationship system-environment do not solve the problema but prolong the irreversibility of the damage for a certain time. The effects of this negentropy are occasional and are limited in time. Finally, definitive negentropy reduce entropy levels due to the correction of abnormalities intra and inter systemic; this negentropy pretends to reach a steady state, because *"living systems, maintaining themselves in a steady state, can avoid the increase of entropy, and may even develop towards states of increased order and organization"* [1].

4. Results and discussion of urban motoring in Mexico

Since its very beginning, vehicles enabled the inter nodal relocation in a territory. In the United States alone the number of registrations rose from 8 to 23 million between 1920 and 1930. At the same time since the middle of 1940 up to the oil crisis in 1973, the number of vehicles increased from 25 million up to more than 100 million units [31]. This information is an indication of the social and financial impact that private vehicles generated in the XX century; and that occurred because a large number of direct and indirect delivery subunits and businesses began to depend of the utilisation of internal combustion engine vehicles. At the same time other types of businesses began to benefit from it as spare parts manufacturers, accessories providers, fuels,

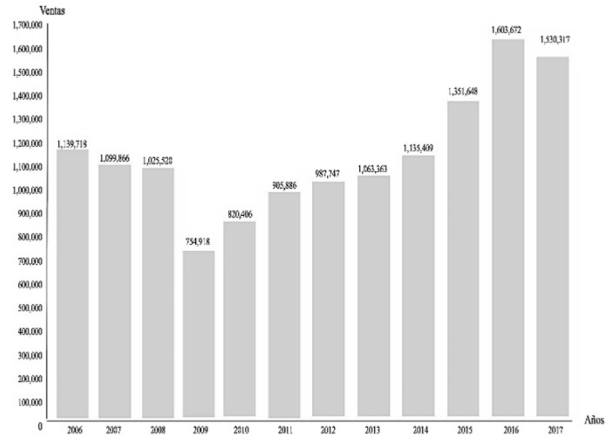

Figura 3. Vehicle yearly sales in Mexico
Fuente: The author. Information reported by [33] was used.

oils and additives distributors; as well as other kind of companies such as credit companies, car dealers, insurance companies, mechanic workshops, electrical and electronic service providers, car-washes, and the like.

In Mexico, nearly two decades after starting the XXI century, internal combustion engine private vehicles continue to be in the social consciousness a symbol of status in connection with their possession. It is believed that it is not the same traveling by private cars in comparison with traveling by bus, or having a new brand car worth USD $7,500 in comparison with a USD $25,000 (or even more expensive) vehicle. In addition, at present private vehicles and related services such as the so called 'shared automobility', or other related activities in the context of 'collaborative economy' are solving occasionaly some abnormalities in the everyday urban mobility but especially in periurban areas.

In 2015, Mexico had around 294 vehicles per 1,000 inhabitants [32] y according to the information provided by the Asociación Mexicana de Distribuidores de Automotores (AMDA), in Mexico the number of light vehicles sold in 2016 was higher compared to what had happened in the previous 10 years; the total number was 1,603,672 units, which included subcompact, compact, luxury, sports, and multiple usage vehicles, as well as light and heavy-duty trucks. Notwithstanding, in 2017 a decreased number of 1,530,317 vehicles were sold, which meant a decrease in 73,355 vehicles, a negative variation of 4.6% in comparison with the previous year (Fig. 3). The forecast for 2018 is near to 1,545,245 units, a 1% increase respecting 2017 [33].

In all Mexican metropolitan cities, the proliferation of private vehicles has exceeded motorways capacity at certain hours of the day, and that occurs due to the disparity between the dimensioning of the physical works and loading excess generated by motorized journeys. However, it is known that widening the dimensions of the motor roads does not solve traffic issues in the long term. After expansion traffic issues can be resolved in a significant way; nevertheless, that occasional negentropy which initially has positive effects in time starts decreasing in effectiveness in reducing negentropy levels.

Private vehicles require matter and energy in order to exist as mechanical, electrical and electronic systems, and in some way understood as autonomous. In summary, the system-vehicle requires of a system-user, and a system-roadway in order to operate for motorized mobility. However, vehicles building industry, and the construction and conservation of motor roads infrastructure, as well as the rapid consumption of raw materials (*not urban*), such as oil materials, row materials for the production of concrete, asphalt roads, additives, paintings, plastic elements, glues, rubber, minerals, water resources, among others, is transforming the homeostasis of these supporting systems. At the same time, in connection with this entropic context it is necessary to add the current trend of horizontal property promotion in *periurban* areas, which implies shortages and deficiencies in mobility alternatives that turn vehicles as the only transportation means able to provide swiftness, comfort, and physical safety, which means a negentropy in the short term [34]. If the above mentioned habitability-mobility trend continues developing in the surroundings of *the urban*, apart from the time factor concern, there would be other serious implications in the structure and infrastructure of the system implying greater risks of accident rates due to the increased and sometimes uncontrolled loads of transit [35,36]. As explained in the attached information about habitability-mobility, habitability sets conditions respecting the most appropriate means to provide mobility in terms of time. Periurban habitability powered by the diffused city model favours the use of vehicles, and that is given due to the lack of infrastructure and alternate transport subsystems. Urban habitability, on the other hand, favours the use of alternative transport means.

4.1. Private vehicles: production and sales forecast

The use of electric vehicles dates back to the middle of the XIX century. These vehicles were produced experimentally before the use of private internal combustion vehicles. However, "*in the 1930´s with the introduction of the internal combustion vehicle, electric vehicles almost disappeared*" [37]. Given the fact that use of electricity was poorly promoted, as well as the introduction of gasoline, added to the fast improvement of internal combustion engines, and weight reduction, electrical vehicles were not produced any more [38]. Sure enough, it has been said that the use of electric vehicles is far superior. Electric vehicles do not depend on the usage of fossil fuels, their efficiency in engines performance is well known, and they produce lesser impact and affectations on the environment [37]. Notwithstanding, "*(…) consumers perceive them to be more expensive due to their higher capital cost*" [39].

In 2011, the International Energy Agency (IEA) estimated there were around 45,000 electrical vehicles in use. In 2012 the figure reached nearly 180,000 units [40]. For 2015, the threshold of 1 million vehicles was surpassed; and in 2016, the number of electric vehicles around the world was above 2 million units. Moreover, the same organization forecasts that the number of electric vehicles will be between 9 and 20 million for 2020, and for 2025 between 40 and 70 million units [41]. In the particular case of Mexico in 2017 a number of 257 private electric vehicles were sold, which is

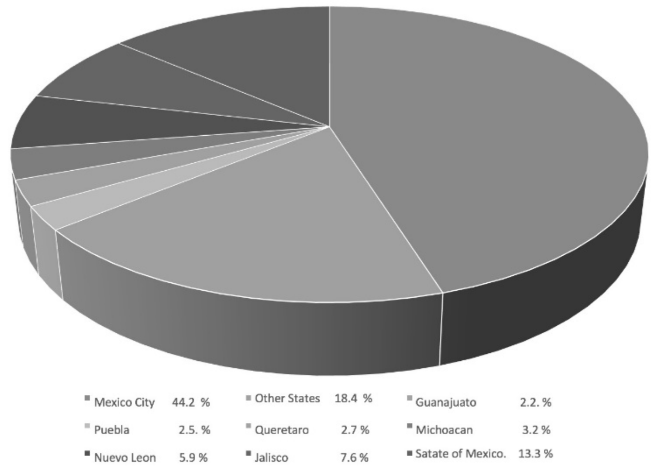

Figure 4. Sales of electric and hybrid vehicles in 2017 in Mexico.
Source: The author. Information reported by [42] was used.

14 private electric vehicles less than in 2016, with a number of 271 units. Notwithstanding, for hybrid vehicles the figure increased from 7,989 vehicles in 2016 to 10,255 in 2017 (Fig. 6) [42].

At considering Figs. 4, 5 and 6, electric vehicles usage trend for the coming decades is growing globaly. However, current vehicle load has become a critical issue in urban mobility of Mexico. Nevertheless, this prospection of vehicle usage it is subject to a number of conditions that would not solve the problem of speed, and commuting time.

4.2. Some urban mobility possible scenarios for private electric vehicles of Mexico

In connection with the variables of speed and time, and urban mobility, two possible scenarios have been identified for private electric vehicles. The first scenario is optimistic and implies an entropy in the subcritical phase. But nevertheless, it is less likely to occur because at present speed

Table 1.
Speed and commuting times for private electric vehicles in Mexico

Variable	Current Scenario	Less likely to occur scenario	Most probable scenario
Speed consumed	Optimistic with sub critic entropy at hours without traffic, and critical entropy at peak hours, or subcritical entropy in both cases	Optimistic with subcritic entropy at hours without traffic and critical at peak hours, or subcritical entropy in both cases	Pesimistc with entropies surpasing the critical phase
Time consumed	Subcritical entropy at hours without traffic and critical entropy at peak hours	Optimistic with sub critical entropies at hours without traffic and critical at peak hours, or sub critical entropy in both cases	Pesimistc with entropies surpasing the critical phase

Source: The autor.

of urban mobility shows significant reductions, and important increases at rush hours. Therefore, it can be said that the current situation of homeostasis varies between subcritical and critical phases; and expecting a scenario where entropy may be constant or reduced in connection with time it is less likely to occur keeping into account the second principle of thermodynamics, and that corresponds to higher estimates in vehicle sales and the consequent vehicles load. The second scenario is pessimistic; with a growing entropy surpassing the critical phase due to the lack of definite negentropies aimed to reduced intra systemic entropy levels (Table 1).

According to the characteristics that identify homeostasis which at present are quasi irreversible, the most likely scenario to occur is pessimistic. There are deficiencies of integrated plans to encourage the use of private non-motorized vehicles to improve urban mobility.

At the same time, there is also a huge lack of balance in habitability-mobility; as well as lack of or absence of infrastructure of sustainable urban mobility systems, and lastly, recurring investments in works to favour the use of vehicles, all of this despite the fact electric vehicles benefit environment in terms of pollutants reduction and noise among others. Nonetheless, due to the excessive use of traditional private vehicles, the processes of substitution of these traditional vehicles in exchange of private electric vehicles, and the consolidation of this means of transport entail entropic forces in the urban system, or negentropic forces with occasional impacts.

The substitution of these private mobility subsystems (internal combustion, hybrid, or electric vehicles), for massive mobility systems such as long articulated busses, electric urban trains, trams, and the like; and the use of mechanical means of mobility (bicycles), pedestrian prioritization; and the systemic interconnection of habilitability-mobility lead to a definitive negentropy, which is required to reduce the current levels of high intra systemic entropy.

5. Conclussions

The conception of *the urban* from the perspective of the systemic analysis implies both the conjunction and the struggle of social, financial, and environmental elements that work as subsystems in the configuration of its structure. The system is transformed by its anthropogenic activity, in other words, embodies a shape, which sometimes faces troubles, worsens and self regulates due to, entrance, process or emission of matter and energy coming from the not urban systems, where the shape of the system allows to monitor and measure qualitatively its homeostasis.

Based on the implementation of the EHN Model it is possible to identify the critical phase in which intra-systemic time and speed is found, even though when some entropic actions might be omitted in order to revert the current system homeostasis; that is possible due to the quasi-reversible phase in which is found. For that reason, these actions necessarily require definite negentropies aimed to discourage the use of private vehicles regardless its power source. Likewise, "*(...) the interests of groups that have temporary social representation are greater than the carrying capacity of the system and, therefore, exceed the set of forces that tends to generate negentropy (...)*" [43].

In light of this, the possible scenarios of the time of connection of the speed of private vehicles in Mexico seem to be pessimistic, because at present the daily flow of these vehicles is in the subcritical phase that tends to escalate to the critical phase. For that reason, the introduction of particular electric vehicles does not solve the main problem or solve other secondary problems. In other words, the most important problem is related to the preservation of the current paradigm: automobility is not resolved; and, in addition, secondary problems such as road congestion, the accident rate, pollution and the like, in relation to the speed of the journey in different metropolitan urban systems is neither improved.

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