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Abstract

Energy generation is currently a necessity worldwide, people use it almost every time in countless of applications to fulfill our necessities and increase our comfort. Most of the used energy relies on the fossil fuel production, refinement and distribution, activities that represent a huge damage to the environment and ecosystems. Solar energy production is a popular alternative to generate energy without the risk of irreparably damaging the environment. It does not generate any kind of GHG or CO_2 in the energy generation process.

The advantages of solar energy generation are undeniable, this is why it may seem curious that this kind of technology is not widely used all across the world, and only some countries are the leaders of this technology, implementing systems at a great scale, reducing the ecological impact and even making profit from it.

Mexico is a country whit one of the greatest solar energy generation potential in the world, but somehow this kind of technology represents less than the .01% of the total energy supply, while Germany, having approximately the half of radiation that Mexico receives form the sun, is the pioneer regarding solar energy generation in the world, considering it as a reliable source of energy and investing on big projects to increase the production in the future.

This work addresses this situation from a complex system point of view, utilizing adaptive cycles and panarchy theories to analyze the resilience of the fossil fuel based and decentralized solar energy systems in Mexico and Germany, in order to develop a wider understanding on what are the characteristics of a panarchy to shift the direction of a focal system towards a sustainable renewable based state, while realizing how the conservative and the decentralized solar energy system are part of the same adaptive cycle and act as a single energy system.

Understanding the role of the energy systems in the panarchy provided input to assess the opportunities to make a knowledge transfer between the two countries through technology and policy transfer concepts and ideas, which turned out highlighting the economic and financial deficiencies of the host country (Mexico) to adopt policies as the ones Germany implements.

Mexico has considerable amounts of fossil fuels reserves that allow it to grow as a system for more time before it needs to implement large scale solar energy production measures.

Keywords: Decentralized solar energy systems; resilience analysis; adaptive cycle; policy transfer; panarchy.

Resumen

La generación de energía es actualmente una necesidad mundial, es usada todo el tiempo en innumerables aplicaciones para satisfacer necesidades e incrementar la comodidad. La mayoría de la energía usada se basa en la producción, refinación y transporte de hidrocarburos, actividades que representan un gran daño al medio ambiente y ecosistemas. La producción de energía solar es una alternativa popular para generar energía sin el riesgo de dañar irreparablemente el ambiente. No genera ningún tipo de CO_2 en el proceso de generación de energía.

Las ventajas de la generación de energía solar son innegables, es por eso que puede parecer un poco extraño que este tipo de tecnología no sea ampliamente usada en todo el mundo, solamente algunos países son lideres en este campo, implementando sistemas a gran escala y reduciendo el impacto ecológico e inclusive generando ganancias.

México es un país con uno de los mejores potenciales en generación de energía solar en el mundo, pero esta tecnología solo representa menos del 0.01% del suministro total de energía, mientras Alemania, contando con aproximadamente la mitad de la radiación que México recibe del sol, es un país pionero en generación de energía solar en el mundo, considerándola como una fuente confiable de energía e invirtiendo en grandes proyectos para incrementar la producción futura.

Este trabajo trata esta situación desde un punto de vista de sistemas complejos, usando los conceptos de ciclos adaptativos y la teoría de panarquia para analizar la resiliencia de los sistemas energéticos basados en hidrocarburos y los sistemas energéticos solares descentralizados en México y Alemania, con el objetivo de entender de mejor manera cuales son las características de una panarquia para cambiar la dirección de un sistema focal hacia un estado sostenible basado ene energías renovables, dándose cuenta de cómo ambos sistemas son parte de un mismo ciclo adaptativo y actúan como un solo sistema energético.

Entendiendo el papel de los sistemas energéticos en la panarquia se pudo realizar el análisis de las oportunidades para hacer una transferencia de conocimiento entre ambos países a través de conceptos e ideas usados de teorías de transferencia de tecnología y políticas, lo cual resulto destacando las deficiencias económicas y financieras del país anfitrión (México) para adoptar políticas como las que Alemania implementa.

México tiene reservas de hidrocarburos considerables que le permiten crecer como sistema por más tiempo antes de que se necesite implementar medidas para producir energía solar a gran escala.

Palabras clave: Sistemas de energía solar descentralizados; análisis de resiliencia; ciclo adaptativo; transferencia de políticas; panarquia.

Zusammenfassung

Die Energieerzeugung ist momentan eine weltweite Notwendigkeit, Menschen nutzen Energie zu fast jeder Zeit in Form von zahllosen Anwendungen um ihre Bedürfnisse zu erfüllen und ihren Komfort zu erhöhen. Der größte Teil der genutzten Energie ist von der Produktion durch fossile Energieträger, sowie deren Raffination und Verteilung abhängig - dies sind Aktivitäten, die einen enormen Schaden an der Umwelt und den Ökosystemen verursachen. Die Produktion von Solarenergie ist eine gängige Alternative um Energie zu produzieren, jedoch ohne das Risiko die Umwelt irreparabel zu zerstören. Während des Prozesses der Energieerzeugung setzt diese Energieform keinerlei GHG oder CO_2 frei.

Die Vorteile der Erzeugung von Solarenergie sind nicht von der Hand zu weisen, deshalb mag es seltsam erscheinen, dass diese Art der Technologie nicht in großem Maßstab weltweit genutzt wird und nur einige Länder die Vorreiter dieser Technologie sind, insbesondere in der Einführung von Systemen in großem Maßstab, der Verringerung der ökologischen Auswirkungen und der Möglichkeit damit Gewinn zu machen.

Mexiko ist ein Land mit einem der größten Potenziale weltweit für die Erzeugung von Solarenergie, jedoch stellt diese Art der Technologie nur 0,1 % der Gesamtenergieversorgung dar. Während Deutschland nur ungefähr die Hälfte der Sonneneinstrahlung von Mexiko erreicht, ist es bezüglich der Erzeugung von Sonnenenergie weltweiter Vorreiter, da es darin eine zuverlässige Energiequelle sieht und in große Projekte, um die Produktion in der Zukunft zu erhöhen, investiert.

Diese Arbeit betrachtet diese Situation aus der Sicht eines komplexen Systems unter Anwendung der Theorien von adaptiven Zyklen und Panarchie um die Resilienz von fossilen Energieträgern und dezentralisierten Solarenergie Systemen in Mexiko und Deutschland zu analysieren und um letztendlich ein größeres Verständnis der Charakteristika von Panarchie für einen Richtungswechsel eines Fokalen Systems, in Richtung eines auf Nachhaltigkeit und Erneuerbarkeit basierten Status, zu entwickeln.

Währenddessen konnte festgestellt werden, dass das konservative System und das dezentralisierte Solarenergie System Teil desselben adaptiven Zyklus sind und somit als ein Energiesystem agieren.

Das Verständnis für die Rolle von Energiesystemen im Rahmen der Panarchie bot einen Beitrag für die Bewertung von möglichem Wissenstransfer zwischen den zwei Ländern in Form von Technologie und Politik, um Konzepte und Ideen zu übertragen. Außerdem konnte festgestellt werden, dass die wirtschaftlichen und finanziellen Mängel des Gastlandes (Mexiko) hervorzuheben sind, um ähnliche politische Konzepte wie die in Deutschland einzuführen. Wobei im Gegensatz zu Deutschland in Mexiko eine bemerkenswerte Menge von Ressourcen an fossilen Energieträger zur Verfügung steht, das erlaubt dem Land für einen längeren Zeitraum als System zu wachsen bevor es die Gewinnung von Solarenergie in großem Maßstab einführen muss.

Schlüsselwörter: Dezentralisierten Solarenergie Systemen; Resilienz Analyse; adaptive Zyklus; Politiktransfer; Panarchie.

1 Introduction

Energy is a primary necessity in the system we live in; it is required to perform almost every daily activity. Is important to acknowledge that along the population growth comes a rising tendency for energy in the world (Lewis & Nocera, 2006). Since the 70's, the world have become aware of the high environmental risk that using fossil fuels represents, and a renewable energy boom started (Turner, 1999), but it hasn't reached a significant level to reduce CO_2 and greenhouse gases emissions to the atmosphere.

In Mexico, Almost 74 % of the electricity generated comes from fossil fuels sources (Secretaría de Energia, 2012). This represents a very high percentage of the country energy mix. To rely mainly in one form of energy generation causes several problems such as a lack of energy security and the necessity of a strong transmission and distribution network system (Farrel, 2011).

The need for new ways to implement renewable energy technologies is undeniable, since the damage to the environment is reaching historical dangerous levels.

Energy decentralization is a new paradigm that developed countries like Germany are adopting as a reliable and low impact source of energy production, such as auto consumption solar and wind microsystems. It consists not only in reducing the size of the energy production plants, but also diversifying the energy mix, by giving the opportunity to the renewable energies to increase their percentage in the energy mix (Farrel, 2011).

In the case of Mexico, as a developing country, the use of renewable energies as a major source of electricity is very poor. In 2011, 70% of the electric energy was generated from fossil fuels applications (Secretaría de Energia, 2012). This reflects a lack of infrastructure to invest in new renewable technologies in the future as an important part of the country energy mix.

Mexico's situation regarding solar energy is a very difficult issue to explain and understand. There are a lot of actors and elements interacting with each other. The adaptive cycles and panarchy concepts provide a logic and robust way to describe and analyze the relationships among the elements within a nested system scheme. These concepts were first introduced to describe the relations among ecosystems levels but recently they have been used to describe other disciplines complex systems such as energy generation (Dangerman & Schellnhuber, 2013).

1.1 Objectives

The main objective of this thesis research is to have a better understanding of Germany and Mexico solar decentralized energy systems as complex systems, analyzing their resilience through a qualitative indicators framework and assess the possibility of a transfer.

Secondary Objectives:

- Explain energy systems within an adaptive cycle and locate in which phase they are.
- Through policy and technology transfer theories, if it is possible, propose management measures for the opportunities found through both countries energy system analysis.

1.2 Justification

Mexico requires energy generation for its development, and even though it generates one third of the CO2 emissions that Germany generates (The World Bank, 2015b). It would be a viable option to start an energy transition strategy before the environmental situation gets worse and the problem cannot longer be solved.

The purpose of an energy transition is obviously not to fix a current situation, but is a long term strategy to avoid the growth of the ongoing environmental and economic problem. The faster it starts to get implemented, the faster the results will be noticeable.

Every energy generation process requires a natural resource; processes requiring combustion for generation need fossil fuels, hydro energy needs water in movement, even renewable energy generation requires natural resources such as solar irradiation and wind. Energy production is deeply related with ecosystems since all the natural resources required for the generation are also key elements in the cycle of such ecosystems.

2 Theoretical framework

2.1 Solar energy.

Solar energy always has been considered as a renewable and clean source of energy generation, it is not a question why since it produces useful energy from the greatest and for human age matters unlimited, the sun.

The sun is the main energy source for our planet, not only for electricity but also for every ecosystem and process. The energy from the sun has been used since a long time ago, the 7th century to be exact, with help of magnifying glasses to make fires, to improve efficient housing building (Ã et al., 2011). It was until the early 1800's when it was discovered that solar energy could be effectively used to produce power, by two main means, photovoltaic cells and thermal concentration (Ã et al., 2011).

It was until the late 1900's when solar energy generation started to develop as a reliable source of energy, with large thermal and photovoltaic projects through the world and also reaching continuously higher PV efficiencies (Ã et al., 2011).

Even though there are various applications to take advantage of solar energy, the main use is to produce energy and the two ways to do so is through PV and thermal concentration technologies; these technologies are the most widely used due its high efficiency in terms of obtaining power from the sun.

Undoubtedly solar PV energy generation is the most popular way to produce electric energy; it may be due its popular applications such as aerospace and even toys and gadgets.

Unfortunately in terms of energy mix generation the share of energy produced through solar PV technologies is rather low.

Figure 1 shows the direct normal irradiation received by the earth from the sun, and it is clear that world energy demand can easily be fulfilled only through solar energy generation. Although it is undoubtedly the one most reliable source of energy when only environment and sources shortages are taken into account, this energy has not reached his peak potential of development.

PV has a lot of advantages over others forms of energy generation, such as the lack of emissions over its functioning process, low maintenance, and the most important the fuel is the sun, which is free and relatively inexhaustible. This technology also has some disadvantages than does not allow it to be as reliable as the fossil fuels, this is the intermittence of the source (day and night) and an overall world high price in comparison with other technologies (Mundo Hernández, De Celis Alonso, Hernández Álvarez, & De Celis Carrillo, 2014)

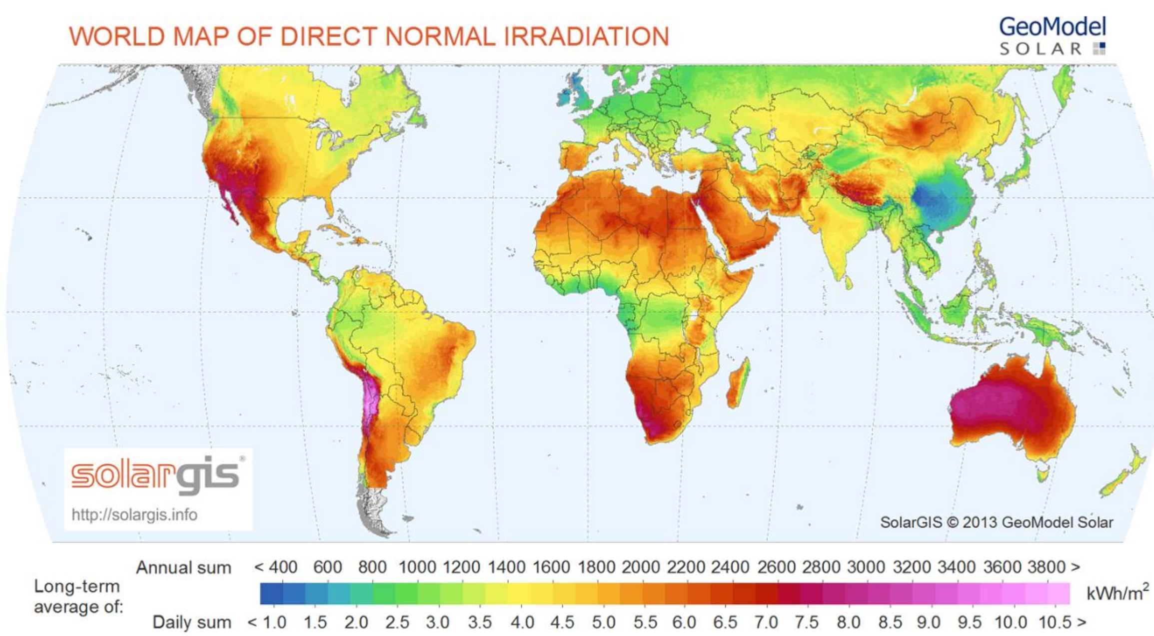

Figure 1 - World Map of Direct Normal Irradiation. Source: (SolarGIS, 2013)

2.2 Decentralized energy systems.

There is a lot of information about decentralized energy systems among all the scientific community, how it is a feasible and sustainable new way of energy generation (Kobayakawa & Kandpal, 2014). Almost every author and scientist talking about this topic considers energy decentralization as a good alternative to turn to but as a big challenge as well. Here is where most of researchers have different opinion and points of view of this alternative, especially on the term “decentralized”. What does decentralized mean in the matters of energy? Sustainability, resilience, economy, policies, environment and community are the most relatable terms to this word, but at the same time most of the authors studying energy decentralization only focus in one or two different terms when they describe it.

As an example Kobayakawa & Kandpal, (2014), review the term of decentralization as a financial and affordability issue, which is a rather important part to take into account to succeed in the implementation of a decentralized energy system, but at the same time in their article, Kobayakawa & Kandpal only consider a decentralized energy system as a mean of rural areas electrification specifically. The study mainly focuses in the balance between financial viability and affordability in the tariff level and how it is a key role in the success of a decentralized system (Kobayakawa & Kandpal, 2014) and it may well be for their study case in rural India, but surely it is not the only one.

Authors Silva Herran & Nakata, (2012) agree in some parts with the previous study, since it also addresses the energy decentralization as a way to provide energy to rural areas, only focusing in different aspects, such as tariff or financial viability. This study addresses also the social issues like poverty as a strong motivation to implement a successful decentralized energy system and how the local supply of resources can reduce costs and increase the reliability. Another aspect that Silva Herran & Nakata, (2012) addressed deeper was the description and calculation of the CO_2 reduction and benefits to the environment originated from the implementation of their proposed local supplied system. Although all of the previous mentioned topics related to energy decentralization by these authors are profoundly important, the most interesting and useful to this research is the argument of the regional disparity. Understanding regional disparity as the huge differences among geographical regions, urban and rural areas, especially in the article's case of study (South America), as well as the income differences, inequality and capacity of the population to acquire a new energy generation system (Silva Herran & Nakata, 2012).

Other studies consider energy decentralization just as a catastrophe event prevention medium, such is the case of León-Camacho, Morales-Acevedo, & Gandlgruber,(2014), they contain the meaning and field of such term inside of prevention and community resilience, in other words the capacity of a community to overcome a natural crisis event and preserve their energy supply system intact and then have a sooner self-reestablishment (León-Camacho et al., 2014).

Several researches have a different point of view regarding energy decentralization, in the way they consider it as a term deeply interconnected to community, and they also link its potential success to the degree of involvement (Wirth, 2014). Community is undoubtedly a key factor in energy decentralization, but it is also an unfamiliar term in the almost techno-economic controlled energy generation field. It was also said that community involvement in the development of photovoltaic in Germany was crucial for the market evolution (Wirth, 2014) and at the same time it was the factor required for the Spanish photovoltaic market success. Author (Wirth, 2014) is so convinced of the community being a main factor in energy decentralization that offers the term of "community energy" as more accurate to define this type of energy generation.

As it was stated previously there are a lot of studies and articles addressing decentralized energy systems, most authors accept the involvement of a lot of factors in order to have a favorable system implementation, but, they only focus in some of them in their respective studies and articles, this may be because of the particular situation of their study case.

A breakdown of the term decentralization is necessary for its complete understanding and its interpretation in regard to this thesis.

Decentralization is defined by the Oxford University Press, (2015) as

/ , "The transfer of authority from central to local government"

0, "The movement of departments of a large organization away from a single administrative center to other locations"

A common ground can be found between these two definitions, both involve time, in the matters that the two refer to a past situation in which something was organized or settled in a central way, a unique center to control a so called system and now it has been transferred or moved to a smaller "centers" organizing their own space. It becomes obvious while reading the definitions, that there are set mainly for a government or organizational points of view, but when the term is appointed to an energy generation issue, the interpretation can be a little difficult to define. There doesn't seem to be a precise universal definition of decentralized energy. What really needs to be decentralized? Infrastructure?, management?, government?, policies?, economy?, market?, etc. The answer is not clear in the literature, but a definition from it can certainly be proposed.

Currently, based on literature, decentralized energy systems focuses in the decentralization of one or two factors mainly, depending on the case of study, but according to the authors the decentralization is surely linked to the factor or factors they consider are more important. Ignoring or not giving enough attention to the system as a whole.

For example the technical factor in an energy system involves, generation equipment, transmission infrastructure, efficiency, energy production, etc. all aspects can be decentralized, but it is obvious that the latter is the main one most people think when a decentralized system is conceptualized. The decentralization of these aspects refers to the local production and consumption, reducing the transmission infrastructure, having smaller equipment, since a smaller load is required, increasing the efficiency through the in-site production and consumption.

It becomes harder to develop on the case of the economy and financial viability, this is because the current economic and financial situation favors the conservative energy system based mainly in fossil fuels and even though it is destined to fail since it is supported by a finite resource, it has become very rigid, in other words it is very hard to introduce a new energy system and very negative to innovation (Dangerman & Schellnhuber, 2013). Dealing with economy and finances is where the term decentralized differs more from the definitions given above, since the economy cannot be decentralized and be operated differently in every energy generating system, the term is understood here as a change in the economy management which can only be done at a great scale. In this current economic state in which a decentralized system can develop, this factor must be discarded, ergo try to work with it not against.

From the definitions above, the term “decentralized energy” does not necessarily limits its area of application towards renewable energies, since it is just an organizational cession to smaller control groups. Some authors like Kobayakawa & Kandpal, (2014) even add to the term the word renewable to differentiate it from another type of energy system which no matter it size and organization is still based on the conservative energy system. To have an accurate interpretation of the term for the matters of this thesis, “decentralized energy” is understood as an only renewables organizational form of generation.

For the social aspect, the main concern is to provide energy to the people living in remote areas and precarious conditions, and through this increase their life quality. In this case the decentralization refers to space, providing autonomous standalone systems to provide energy to people living in hard accessing areas that live far away from the big centers of development, and therefore falling behind.

Referring to the community aspect, the decentralization is addressed as community organization with the common objective of generate their own energy through their own management and/or investment, being interrelated with the system and having the feeling of commitment towards it (Wirth, 2014) and also the environment.

Regarding the policies, decentralization refers to a solid policy development and implementation; it has to be specific to the place requirements in several dimensions such as time and economy. This topic will be additionally analyzed in the development of this framework due its high degree of complexity

To sum up the different perspectives and approaches interpreted from the literature, in this document, a decentralized energy system will be considered as synergic combination of key factors and each one of them can be “decentralized”, therefore a decentralized energy system can be broken down and all the factors can be analyzed separately and functioning as a whole system as well.

This thesis will be focusing mainly in decentralized solar systems, since it is the more divergent type of energy generation between the two study cases countries, (Mexico and Germany).

2.3 Resilience and adaptive cycles.

The term resilience was first added to the English language in the 17th century with the simple meaning to rebound or recoil (McAslan, 2010). It was until 1818 when the term started to be used as an adjective to describe the capacity of wood to withstand certain kinds of loads (McAslan, 2010), then the application of this definition spread through the civil engineering and material sciences, later evolving into several different interpretation among authors, but all coinciding on the ability to withstand something, such as impacts, loads, time and extreme wear (McAslan, 2010).

It was until 1973 that the term was used in ecology to describe a property of an ecosystem (McAslan, 2010). Holling, 1973, describes in his work “Resilience and Stability of Ecological Systems” resilience as “a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables”. Without doubt this definition is more convoluted than the given previously, since it involves systems which themselves raise a lot of clarifying questions and can compose an entire different topic; then it states the involvement of change and disturbance, not specifying what kind or magnitude; and at last it addresses the main issue, maintaining the relationships among the main actors in an ecosystem.

The ecosystem is certainly the most complex system there is, with an almost immeasurable number of interacting factors, fluxes, feedbacks and actors interacting with each other throughout space and time it isn't a surprise that Holling´s interpretation of resilience in the field was very well received, it's very appealing to describe such complexity, therefore the term was widely used and interpreted by several authors to describe this unique ecosystem property (Table 1) (McAslan, 2010).

Table 1 - Ecological definitions of resilience. Source: (McAslan, 2010)

Author	Definition
Holling, 1973	Resilience of an ecosystem is the measure of the ability of an ecosystem to absorb changes and still exist.
Pimm, 1984	Resilience is the speed with which a system returns to its original shape
Holling et al., 1995	Resilience is the buffer capacity or ability to absorb perturbation, or the magnitude of the disturbance that can be absorbed before a system changes its structure by changing the variables and processes that control behaviour.
Alwang et al., 2001	Resilience is the ability to resist downward pressures and to recover from shock. From the ecological literature – property that allows a system to absorb and use and even benefit from change. Where resilience is high, it requires a major disturbance to overcome the limits to qualitative change in a system and allow it to be transformed rapidly into another condition.
Alkers et al., 2002	Resilience is the potential of a system to remain in a particular configuration and to maintain its feedbacks and functions, and involves the ability of the system to reorganise following the disturbance driven change.
Cardona, 2003	The capacity of the damaged ecosystem or community to absorb negative impacts and recover from these.
Resilience Alliance, 2005	Ecosystem resilience is the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes. Thus, a resilient ecosystem can withstand shocks and rebuild itself when necessary.
Stockholm Resilience Centre, 2009	Resilience refers to the capacity of a social-ecological system both to withstand perturbations from for instance climate or economic shocks and to rebuild and renew itself afterwards. Loss of resilience can cause loss of valuable ecosystem services, and may even lead to rapid transitions or shifts into qualitatively different situations and configurations, evident in, for instance people, ecosystems, knowledge systems, or whole cultures.

It is now clear that the latter resilience interpretation is profoundly connected to the dynamics of a system, which, using the ecosystem example, have successions, in other words, the characteristic of the current system state to give space to another to develop and pass through specific phases of exploitation, (r) and conservation, (K) (Gunderson & Holling, 2002). The exploitation refers to a phase in a system where rapid colonization, hence development, is emphasized, and conservation describes the phase where the capital, material and energy are progressively accumulated (Gunderson & Holling, 2002). For the better understanding of such complexity the ecosystem possesses, the necessity for more phases between conservation and reorganization arises (Gunderson & Holling, 2002). In 2002 Gunderson & Holling, described two more phases, release (Ω), adapting it from the concept "creative destruction", from the equivalent system in economy that matches the recession stage where the innovation from the previous state has no longer effect and the field is open for entrepreneurs (SAAD) and reorganization (α), referring to a state welcoming and putting to work innovation and ideas, therefore a new organization of the system.

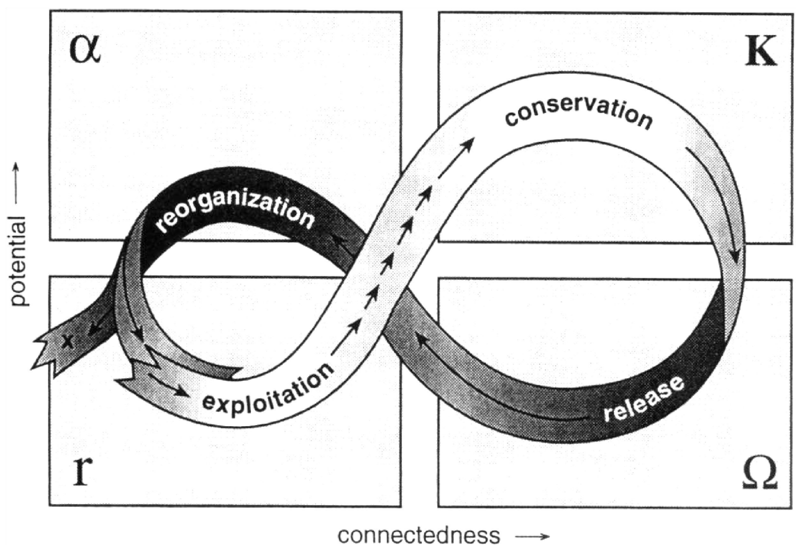

Figure 2 - Graphic representation of the adaptive cycle. Source: (Gunderson & Holling, 2002)

The fluctuation of a system among these phases is known as the adaptive cycle (Gunderson & Holling, 2002). Figure 2 shows a graphical representation of the adaptive cycle and the direction and order of the phases of it, wavering trough two axes, potential and connectedness. The potential refers to the limit of what can be possible and the relation between the axes and the phases can be explained through the direction line of both, back and front loops independently. As a system passes through the exploitation and conservation phases, which is the slowest transition, both characteristics increase, the potential starts getting accumulated, and the systems relations strengthen, developing a high connectedness (Gunderson & Holling, 2002). The back loop corresponds to the transition between the reorganization and the release phases, which happen very fast after the conservation phase has reached its limit peak of growth and accumulated potential gets suddenly liberated, in this stage, the connectedness of the system decreases while the potential increases again giving space and opportunity for innovation and for a new system setting, before establishing it and passing again to the exploitation phase. In figure 2 an alternative output can be seen between the reorganization and exploitation phase marked with an “X” this output refers to certain element of potential, lost beyond recovery from the last system state, which due its long extension throughout the conservation phase, became extremely rigid and could not adapt to a new system setting, this potential is now lost and cannot longer be part of the new system state.

Once all the phases from the adaptive cycle are clear as well as the axes, an inquire rises: the exact place or role of the resilience among all these elements might seem a little lost. To have a better understanding of the resilience within the adaptive cycle, it has to be consider it as a third axis or third dimension, which grows along the back loop, reaching its highest value in the reorganization phase (α), where the system welcomes innovation and opportunities having potential for a new system setting, regardless the low connectedness in that phase. Figure 3 shows the fluctuation of the characteristics of the adaptive cycle through time and how they differ among phases.

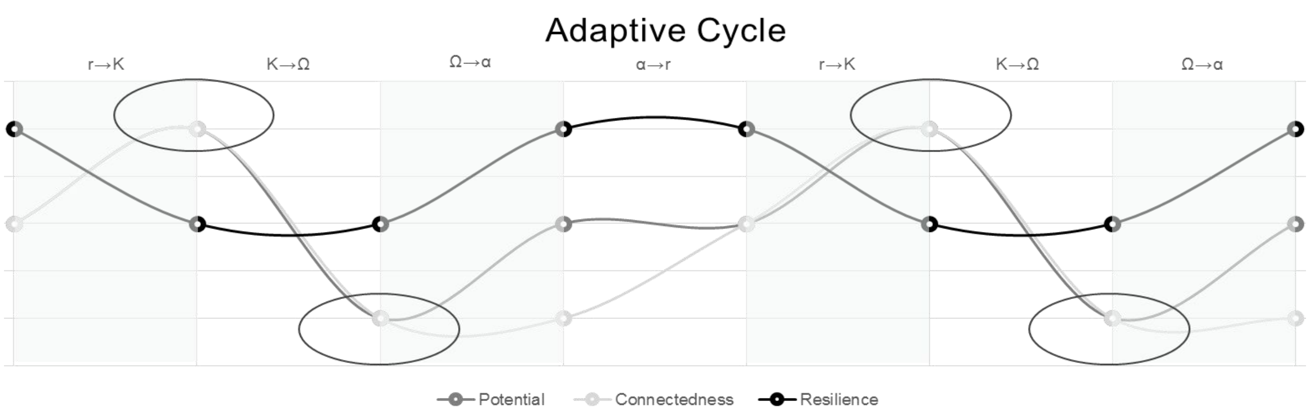

Figure 3 - Adaptive cycles dimensions graph. Source: Own elaboration with information from (Gunderson & Holling, 2002)

2.4 Traps

The success and the peaceful subsistence of a socio-ecological system such as the energy generation, resides in its variability, it is an essential characteristic for its maintenance (C.S. Holling, 2001). Without the variability of the three characteristics (connectedness, potential and resilience), the system enters into a place outside the healthy path through the phases of the adaptive cycle.

As it is shown in Figure 3, a system wavers among phases, increasing and decreasing the strength of the characteristic as it goes. The potential, connectedness and resilience are never together at very high or very low levels; of course this scheme only considers an ideal normal system, but sometimes under certain situations a system can get into the so called “traps”, therefore becoming a maladaptive system (C.S. Holling, 2001).

There are two types of traps, poverty and rigidity traps (Gunderson & Holling, 2002). The system may enter into a poverty trap when it is passing from the conservation phase (K) to the release phase (Ω). In a system with a normal flux among phases, all the potential is released and at this point connectedness reaches the lowest level, then it quickly reorganizes. The motive for the phase changing may not be only caused by the system processes themselves, but it also can be induced by a misuse or external force that not only liberates the potential, it may eliminate it, getting into a situation with low potential, low connectedness and low resilience, this situation collapses the adaptive cycle which can start a general collapse at all levels (C.S. Holling, 2001). The case of the rigidity trap presents a totally different situation from the one described for the poverty trap, the system may enter in it when the system is between the exploitation (r) and conservation (K) phases, potential, connectedness and resilience, reach a rather high level. In this state the system accumulates large wealth and it’s very well organized and managed, becoming extremely resistant to extern disturbances and rigid to change, banishing innovation and new technology (Gunderson & Holling, 2002). The system rotates in the same K phase over and over, stopping the adaptive cycle to follow its natural course (Gunderson & Holling, 2002). The real danger of this kind of trap is that the collapse is imminent and as the conservation phase prolongs, the possibility to have not only an important collapse but a crisis grows by the moment. In Figure 3 the “danger zones" to fall into the traps are identified with black circles within the adaptive cycle fluxes.

2.5 Panarchies

After understanding the logics and behavior of a system within the adaptive cycle, it is simple to try and analyze it with this course of thought, but something has to be considered before doing so, even though a system may have exclusive elements, relationships and processes, they always affect and get affected by other systems. Socio-ecological systems function in different levels of space and time, there can be slow and enormous systems even at a planetary level, and also be limited in space of operation and fast changing like a small ant colony in a backyard. The systems can me studied together through organization in a hierarchy, this task is very difficult especially when the system is being considered from the adaptive cycle point of view, which uncertainty is a milestone in its definition. In 2001, Holling dealt with this impasse adopting the word "*panarchy*", etymologically meaning "*unpredictable hierarchy*", and defined as: "*A representation of a hierarchy as a nested set of adaptive cycles*". Figure 4 shows the hierarchical setting of a panarchy within space and time.

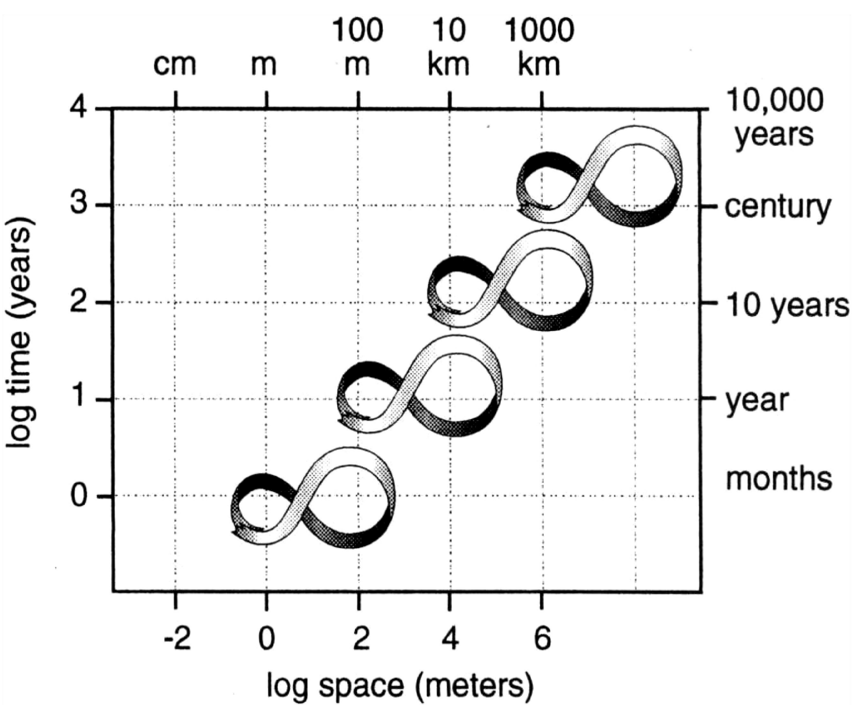

Figure 4 - Hierarchical setting of a panarchy within space and time. Source: (C.S. Holling, 2001)

There are relationships among the involved systems inside a panarchy, which can affect their phase changing or stabilization. Two main relations exist among levels. The first one is when a medium sized system is affected by a small and fast one, (revolt) , the latter just changed to the release phase (Ω) and can affect the medium sized system, especially when it is in its conservation (K) phase, inducing a collapse and forcing it to change to the release phase (Ω), this type of relation among levels can be very dangerous, since it can develop into a domino effect, generating a crisis in all levels (C.S. Holling, 2001). The second kind of relation among levels is the so called "remember" which examines the interaction among a medium sized system with a bigger and slower one, it happens when the latter influences the other when it is the reorganization phase (α). While the medium sized system is open for innovation and has a large potential to develop into a new state, the large system which is in a conservation phase (K) influences it proposing some of its own characteristics and elements in the search for the new state, (Figure 5) (C.S. Holling, 2001).

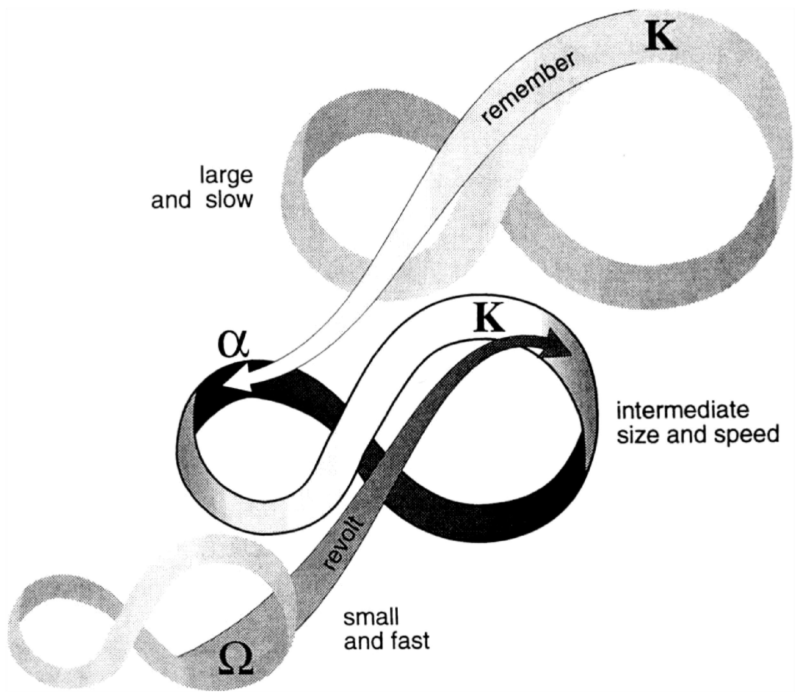

Figure 5 - Panarchical connections. Source: (C.S. Holling, 2001)

2.6 Adaptive cycle in energy system

Dealing with an ecosystem property as inclusive as resilience is, it becomes almost impossible not to consider a very crucial factor in the ecosystem which is the human being. The inclusion of this actor to the ongoing explanation is necessary and at the same time lightly problematic, the human sciences have an extremely wide field of study with a lot of subdivisions within other disciplines, but undoubtedly the main dependent relationship is with the ecosystem which provides us with goods and services.

Resilience is now a word with several definitions in different disciplines, including human sciences, but always having the same core idea. For example the term is used in psychology as “the capacity to withstand the impact stressors and fight stress” (McAslan, 2010), again a property or characteristic of, in this case a person to overcome an emotional situation.

Resilience has also been used in corporate strategy, assembling the concept of “enterprise resilience” which refers to risk management strategies and their incorporation to the everyday operations (McAslan, 2010), again, trying to overcome a disturbance without losing the current state.

Since the complexity given to the concept resilience, it became very popular and that is why it started being used to analyze systems with similar ratiocination to the adaptive cycle.

In 2012 (Dangerman & Schellnhuber, 2013) proposes a different view of the unsustainable industrial metabolism, analyzing the current world energy system as well as the alternative (renewable), through adaptive cycles and panarchy theory.

It’s impossible to separate the energy system from the economy and technology. The first one simply because energy generation is the largest business in earth, and the success and implementation of both energy systems, the conventional and the alternative, is deeply linked to their behavior in the market (Dangerman & Schellnhuber, 2013). Technology has been a milestone element in energy generation since it has had to develop parallel to the factors that increase energy demand such as population an

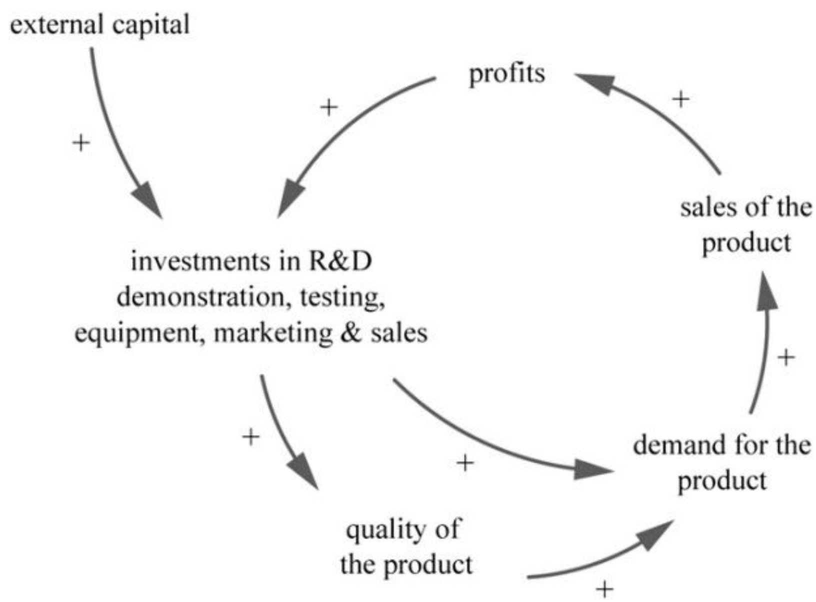

Figure 6 - Core Reinforcing feedback loop in technology. Source: (Dangerman & Schellnhuber, 2013)

economic growth in the last decades. The behavior of both systems regarding economy and technology has followed the same scheme, utilizing external capital to generate investments in resources and development (R&D) of the technology, having a demand of the product, selling it and investing again to increase its quality, obtaining each time more feedback to improve it (Dangerman & Schellnhuber, 2013), as it can be seen on Figure 6.

The previous explanation raises a query about the huge difference between the development and success among energy systems, if both follow the same behavioral scheme, why the conventional fossil fuel exploiting one is quite more rigid organized and developed than the alternative one?. The answer lies in the time; the conventional energy generation system has a huge difference regarding time of operation comparing to the relatively new alternative system, all this time has allowed the conventional system to grow very rigid and organized, rejecting and retaining other technologies from developing (Dangerman & Schellnhuber, 2013). The previous situation between two systems is expressed by (Dangerman & Schellnhuber, 2013) as the “successful to the successful” archetype, as it can be seen in Figure 7, this archetype shows that no matter the efforts of the other technology to gain success or in terms of the adaptive cycle, potential, the system is highly connected only to its own elements and does not give a real opportunity to the new system to develop. This is a clear example of a system falling into the rigid trap therefore becoming a maladaptive system.

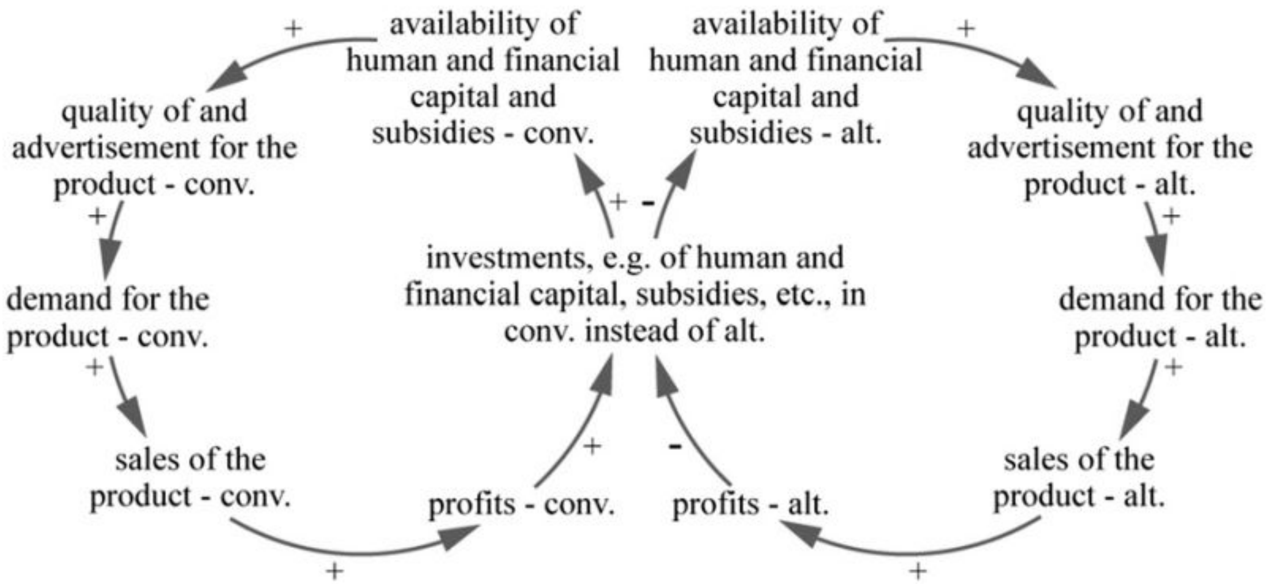

Figure 7 - "Success to the Successful" competition between conventional (conv) and alternative (alt) energy technologies. Source:(Dangerman & Schellnhuber, 2013)*.*

(Dangerman & Schellnhuber, 2013) uses the concepts of adaptive cycles, panarchy and resilience to describe the complex interactions and dynamics of the energy system. He proposes a panarchy of nested adaptive cycles, assembled by both energy systems, the conservative and the alternative, the financial system, the environmental system and the decision and policy makers.

As can be seen in Figure 8, Dangerman & Schellnhuber (2013), define the ecosystem adaptive cycle as the slowest and largest of all, the energy and financial systems in the same position regarding speed of changing among phases but obviously different respecting space, being the alternative energy system the smallest, the financial system in the middle and the conservative system as the biggest of the three. The last but not least is the decision and policy makers adaptive cycle which is the one that has the fastest changing ability and the least people and space involved in its functioning.

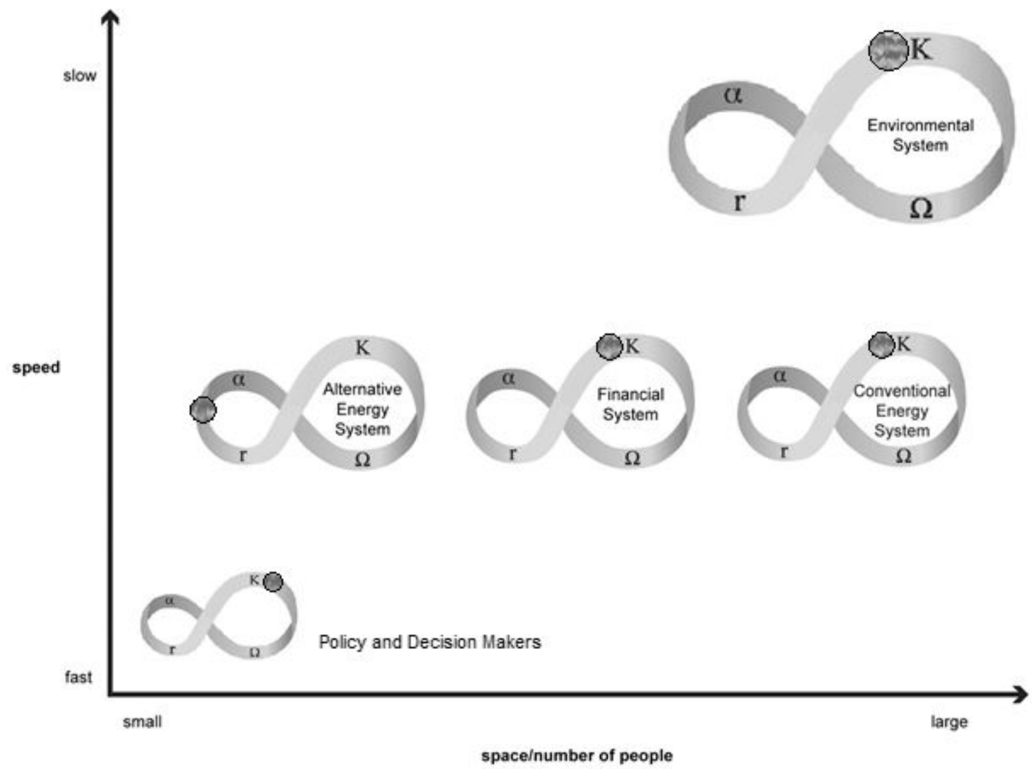

Figure 8 - Key relationships of the various systems visualized in a panarchy depiction. Source: Modified from (Dangerman & Schellnhuber, 2013)

According to Dangerman & Schellnhuber, (2013) the main problem to succeed and produce a change of phases in the energy systems is the position of the shareholders which have very limited liabilities in terms of damaging the environment system, this blocks the bad feedback from such system to the financial and conservative systems, prolonging their stay in the conservation phase and becoming even more rigid, (Rigid Trap). Of course the legislation to improve this shareholders autonomy situation lies on the policy and decision makers, and even though they are the fastest changing adaptive cycle in the panarchy, they have a tendency due their leaders interests to keep the financial and conventional energy systems in their conservative phase as long as possible, (Figure 8).

Thanks to Dangerman & Schellnhuber's (2013) analysis, the phases where all the systems are within their respective adaptive cycles, for example the conservative energy system is getting stuck in an overextended conservation phase, since the fossil fuels consumption as a main option for energy generation, is still in the first place worldwide, with developed countries overexploiting the resource to maintain their status, and developing countries starting to use more each time to obtain an international competitive economic level (Dangerman & Schellnhuber, 2013). The financial system is obviously in the same place as the conservative energy system, a late conservation phase, this behavior is very logic and predictable since both system are linked and depend on one each other, since energy is the biggest business on the world (Dangerman & Schellnhuber, 2013). Regarding the alternative energy system, its change of phases from the reorganization to the exploitation is being stopped by the tightness of the previous two systems, and getting not much support from the policy system (Dangerman & Schellnhuber, 2013). The policy adaptive cycle is the fastest and the smallest and, although it does change phases, these changes only have superficial influence over the alternative energy system, being that the “innovation” only allows the conservative energy system to develop new ways to keep maintaining itself in the conservation phase.

Dangerman & Schellnhuber (2013), only take into account three adaptive cycles affecting the energy systems: financial, policy and environment and even though his description and representation of the panarchy is very accurate, there is an element lacking, which is present in all levels of the panarchy, hence rather important to take into account, this element is community involvement.

Community involvement is one of the main characteristics of a healthy resilient system (Bahadur, Ibrahim, & Tanner, 2010).The importance of this factor is undoubtedly required to have a complete view of the world energy systems, it can or could have strong influence in every level of the panarchy, since a social system has a wider span in space and time to function as an adaptive cycle than other systems, as is shown in Figure 9. Community involvement is a key element to start an energy transition from centralized to decentralized generation (Wirth, 2014), increasing this way the diversity in the system, therefore the resilience.

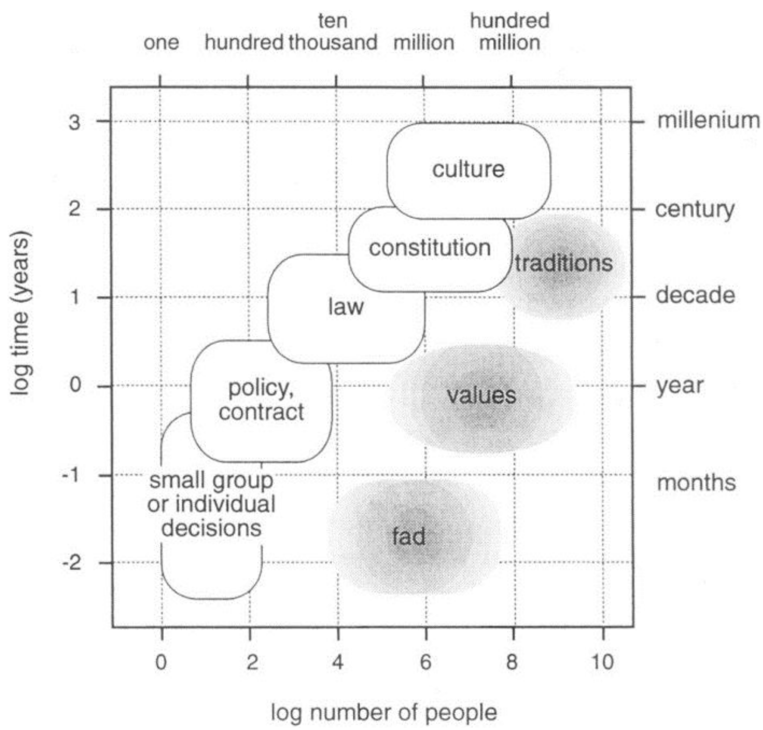

Figure 9 - Institutional hierarchy of rule sets. Source:(C.S. Holling, 2001)

All these interrelations among the levels of the panarchy lead to the fact that the world alternative energy system will have neither space nor time to develop into a reliable source of energy if there is no change of phases in the conservative energy system, in other words, the conservative energy system must change entirely its organization at all levels in order to give opportunity to the alternative system to become a feasible option for the future.

2.7 Transfer concepts and methods

2.7.1 Technology transfer

According to Mohammed Saad (2000) the technology transfer concept is based in the fact that: “Technological change is a key factor in economic growth, industrial change and international competitiveness”. The previous statement raises many inquiries, for example what are the definitions and interpretation of “technology” and “change” regarding technology transfer.

Technology is often considered as a tool, or a single element to enable the reaching of a specific goal (Bozeman, 2000), but that may not be a complete perception of the word, since it has a larger depth of influence in its application. Technology must be considered as a set of processes carried out in order to reach a goal, it is important to highlight that the term also involves knowledge to put in practice such processes, which is why in terms of technology transfer, technology and knowledge are bonded and inseparable concepts (Bozeman, 2000).

Regarding the interpretation of the word “change”, for the purposes of this study, will be considered as a renovation process in which innovation plays a key role to induce this transition (Saad, 2000).

This is the techno-economical “version” of the adaptive cycles previously explained, here the disturbances that induce the system to a necessary collapse is represented by innovation, which in this analogy is expressed in terms of R&D and learning (Saad, 2000).

Technology transfer is considered as a method, that mostly developing countries use to implement proven successful practices in order to increase the economic growth as well as the improvement of the industrial development (Saad, 2000).

Innovation is the main element of change in a technology transfer process. As simple as the word may seem, innovation can be a tough concept to understand and absorb, since technology transfer has to be able to cope with all the disciplines involved in development, is just logical that the process of innovation must incorporate this multi-field approach (Saad, 2000).

Addressing the process of innovation from a multi-disciplinary approach not an easy task, as Figure 10 shows, the convergence of six involved disciplines in the process of innovation to obtain a common goal as an only output is really difficult (Saad, 2000).

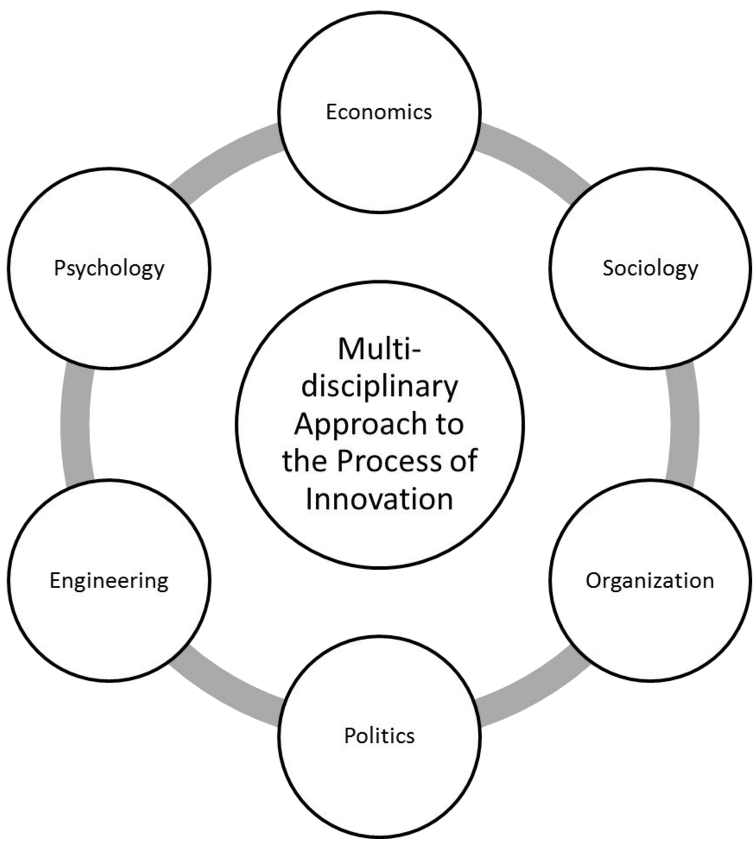

Figure 10 - The study of innovation. Source: Modified from (Saad, 2000)

Innovation is a highly complex and long process itself, which sparks the development through technology transfer. Many authors have tried to identify the main stages within innovation process, a hard task since its complexity lies in the interaction and feedback management of such stages (Saad, 2000).

Saad, (2000), proposed five main stages to describe the process of innovation: "*Identification of the need to innovate, developing awareness, selecting the innovation, planning and implementing*".

To identify the need to innovate is essential to have an open environment towards feedback from the awareness and acknowledgment of a need. The inclusion of all factors such as politics, economy, society, culture and environment, is vital to make the right decision. The developing awareness stage is crucial to lay the foundations of a successful technology transfer, the concept points out the necessity to get to know the new introduced idea, to develop experience and, therefore avoid the chance of having a situation where the host environment rejects it. It is not very common to face a situation where the technology and the host environment have the same matching characteristics, most of the time they are different, here is where the next stage becomes useful, selecting the innovation, refers to a deep analysis of strengths and weaknesses among the technology and the host to identify the possible outcomes of the implementation obtaining alternative innovations, and then selecting the best one, considering its capacity to cope with the host and to fulfill the need. Planning represents the middle stage between the conceptualization of the idea and the implementation; it focuses mainly in the anticipation of possible events happening after the implementation and how to handle them in the best way. At last but not least, the implementation stage, where all the conceptual work gets put to practice, and where the innovation starts developing in a new environment (Saad, 2000).

An innovation process as well as for technology transfer, the dynamicity has to be part of their nature, constant change and adaptation to shifts of the host environment conditions is key to continue having success in its implementation (Saad, 2000).

In most of the application the concept of technology transfer refers to industrial applications, nevertheless since the economic and innovation system it is based on resembles the adaptive cycle, theories will be discussed.

Technology transfer requires a potential to welcome innovation and also a set of characteristics to succeed, this characteristics (Figure 11). Similar to a computer structure, the first two characteristics required are hardware and software, in this matter, hardware refers to the entire physical infrastructure required for the technology while software refers to the knowledge requirements to implement this technology. Brainware is linked to hardware and software, in the sense that it also highlights the necessity for knowledge but not only for application, but also for the synergy among them as well as their justification. Support net is the fourth characteristic to have a successful technology transfer, and it addresses the issue of having a strong complex network to back the technology up and allow it to develop in the new environment (Saad, 2000).

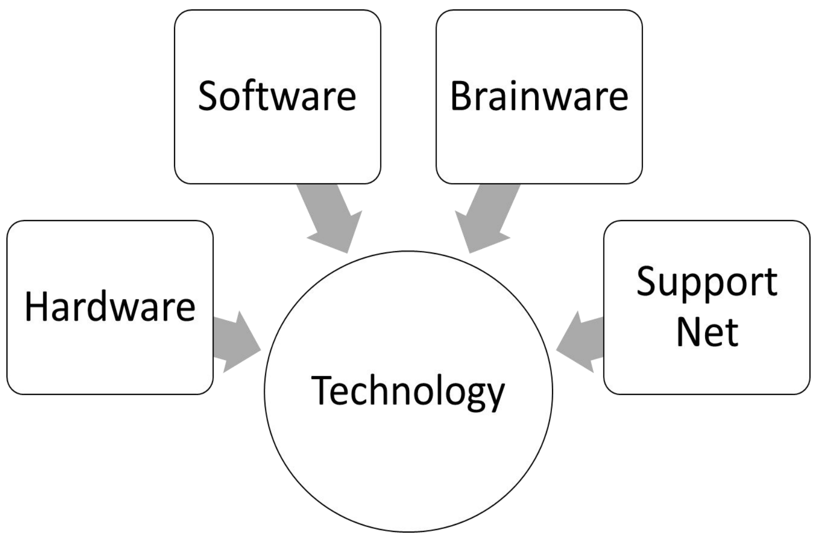

Figure 11 - The main components of technology. Source: Modified from (Saad, 2000)

2.7.2 Policy transfer

As it was stated before, technology transfer is, roughly, a multidisciplinary process to implement a technology in a developing country from another more developed country, mostly in an industrial point of view. Policy transfer also consists in a process, through which successful policies are “exported” from a county to another. The multidisciplinary singularity of the technology transfer may represent a difficulty for its development and understanding, but at least it addresses de issue of necessity of include as much factors as possible (Saad, 2000). Dealing with policy transfer, most of the cases, the feasibility analysis, the studies of the host and the policy are put together by three main actors: state, international organizations, bureaucrats and politicians (Stone, 2001). The previous actors are official, and they rely in a coercive way of implementing new policies through formal decision making, regardless of that this kind of policy transfer at a global level, is more predominant and common (Stone, 2001).

On the other side of the coin, there are the so called “knowledge actors”, like NGOs, training institutes, scientific associations, foundations and consultants, which address the policy transfer issue as a voluntary process, relying almost completely on the knowledge obtain through research, studies and experience. This second type of policy transfer started to gain popularity on the early 00’s, especially among Europe and American researchers (Stone, 2001). It is important to highlight that although this kind of transfer is based on a voluntary implementation, sometimes this knowledge actors are involved in coercive measures.

In 2001, Diane Stone assessed the difference among these two types of technology transfer, remarking the importance and attributes of each one, the strength and connectedness of the state based process and the extensive knowledge about the policy and the receiver obtained through the knowledge process (Figure.

A policy network takes into account actors from both types of policy transfer involving them into debates, workshops and research about the policies trends, diffusion (spread of the policy) and convergence (same policies in similar conditions countries) in relevant study cases (Stone, 2001).

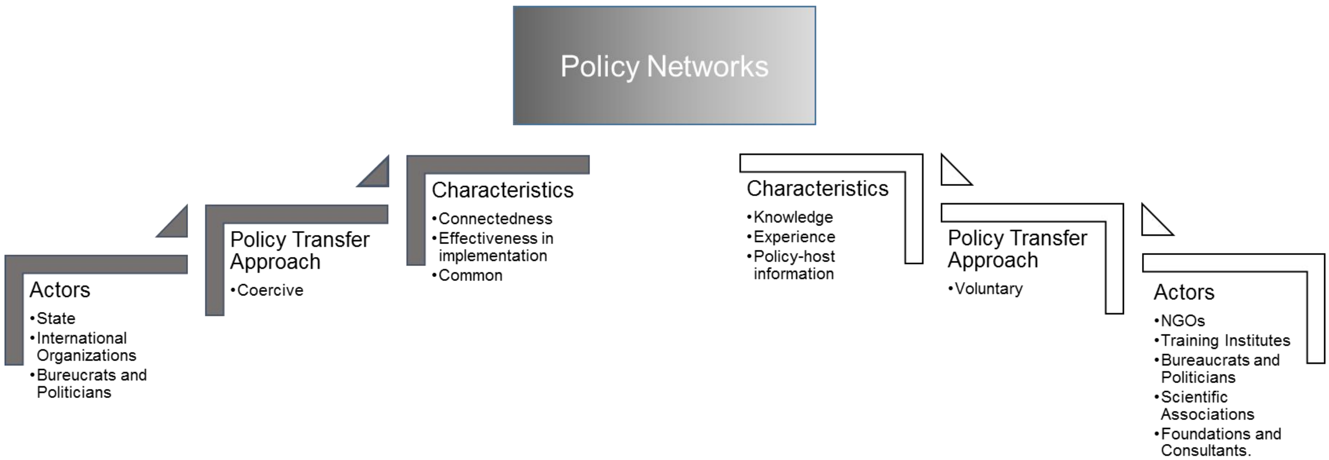

Figure 12 - Policy transfer approaches convergence in Policy Networks. Source: Own elaboration with information from (Stone, 2001)

One example of policy network is the global public policy network (GPPN), educational based, integrated by seven, both, public and private institutions across the world. Among their principles are public policy research, education, address social problems, policy interventions design, and orientation towards public and private sectors, as well as nongovernmental (GPPN).

An example of an energy global policy network is the Renewable Energy Policy Network for the 21st Century (REN21, 2015), which main focus is the energy transition through renewable energy systems implementation. This network is widely recognized as an organization that puts together key actors from all sectors such as NGOs, governments, international organizations, universities, industry and research-academic institutions to address the issue of implementing renewables to proceed to a fast an effective energy transition (REN21, 2015).

3 Methodology

The methodology to carry through this thesis will follow the following steps:

3.1 Definition and delimitation of the systems.

First of all, the systems that will be analyzed through this method are the so called conservative energy system (Dangerman & Schellnhuber, 2013) and the decentralized solar energy system in both cases, Germany and Mexico. The deep multidiscipline analysis of the proposed energy systems that features the energy generation is required to complete the next step data matrix and assess their resilience.

The systems will be described using qualitative and quantitative information emphasizing the main influences of other levels systems and their interaction. The focal systems are the conservative and the decentralized solar systems, and the systems considered in other levels of the panarchy will be:

- Environmental System – This system will be analyzed in the panarchy as the largest and slowest, and only in regard to the main energy generation disturbances at a global scale over the environment, ergo GHG emissions and CO_2 concentrations in the atmosphere.
- Financial Economical System – Its main focus is economic efficiency, as well as the relation among shareholders responsible of the investments towards new technologies and their influence on the energy system.
- Policy Development System – This system consist in all the actors responsible for developing policies about the countries energy generation, what are the real aims and influences to develop new energy policies.
- Social and Community Involvement System – Basically this system consist in the social cohesion, and having a different awareness as communities, empowering and believe that change can happened starting with small steps among individuals. Social acceptance towards new technology and policies is also a milestone for this level development.

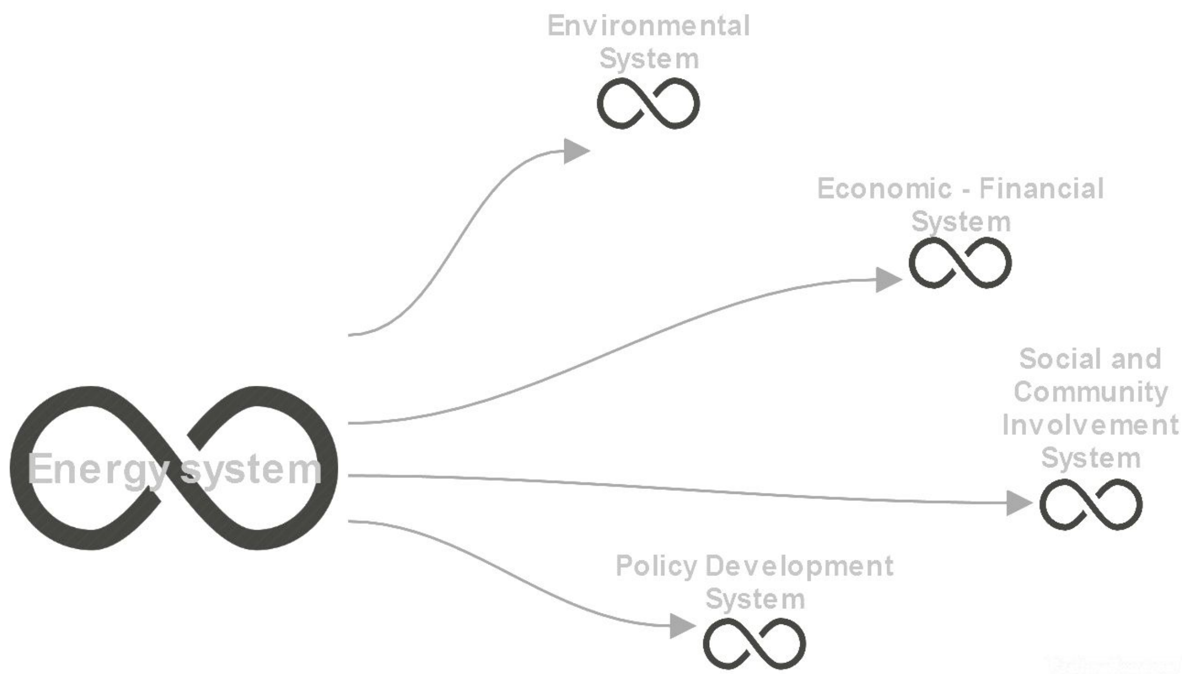

Figure 13 - Energy system subsystems. Source: Own elaboration.

The status of the energy system in both countries, carried on by the definition of the previous mentioned 4 subsystems (Figure13), will be needed to complete accurately the indicators matrix in the next step. The systems will be analyzed and defined qualitatively taking into account key independent elements within them to be able to assess their resilience later on.

As it was stated in the theoretical framework, the interpretation of the word decentralized varies, but for the matters of this thesis, a decentralized solar energy system will be considered as a system that does not follow the strong tendency of the conservative energy system that relies mainly on one source of energy to produce electricity, commonly fossil fuels, therefore the decentralized solar energy system is any implementation of a technology to obtain energy from the sun, "decentralizing" the way obtaining energy from only one source.

3.2 Resilience analysis of the conservative and solar energy systems

The resilience is a very subjective word in terms of measuring it that is why the adaptive cycle and panarchy theories are going to be used to analyze the resilience of both energy systems, conservative (fossil fuels) and decentralized solar in Mexico and Germany. The resilience analysis will be made through resilience indicators. The indicators used in this analysis will be modified from the ones previously used in another resilience analysis thesis by Riveros Ospina (2013), whom used them for the assessment of the sustainability in a specific case in the Colombian Caribbean. The author used the following indicators to locate accurately the focal system in the adaptive cycle phases separating them in three characteristics: Resistance, Adaptability and Transformability, and will be measured with a qualitative scale of five levels: Very Good, Good, Tolerable, Poor and Very Poor, (Riveros Ospina, 2013). There are some similarities between the analyses, but the main object of study is totally different that is why the indicators measured in this thesis will be modified as it follows:

Resistance:

- Diversity - This indicator measures mainly the quality and options of the energy system to resist change, the storage of resources to maintain the energy system as it is.
- Synergy of the Elements – Measures the degree of involvement of all the elements in the focal system to fulfill the energy demands.

Adaptability:

- Dynamicity – This indicator is highly important since it asses the ability of the elements forming the focal energy system to stand by their own, decentralized or in different configurations and succeed to still providing energy as well as keeping itself from collapsing.
- Learning – As it is inferred from the title, this indicator measures the capacity of the system to learn from past errors and also from the

accomplishments. The ability of the system to have a wider view of all the levels of the panarchy and their influences among each other (remember and revolt).

Transformability:

- Preparedness – It is all about the feedback management, quality and speed wise, it also measures the effectiveness and/or existence of backup plans against a disturbance.
- Innovation – This indicator assesses the capacity of the energy system to embrace change through innovations and new technology when facing disturbances, hence, at what degree the systems welcomes new technology as an option to face disturbances.

3.3 Phases of the adaptive cycle

Once all four indicators matrixes are filled, all four energy systems are going to be placed into an adaptive cycle, defining in which phase they are. This part will be made comparing the characteristics of the phases in their three characteristics dimensions, (potential, connectedness and resilience) with the systems status obtained in the previous step. The positioning of the energy systems in the adaptive cycle gives a deeper understanding of them as a part of the panarchy, as well as a clarification on how the external systems influence them and their current track through the cycle.

3.4 Technology and policy transfer potential

Technology and policy transfer are processes which are implemented by developing countries from successful cases in developed countries. Both processes are relatable to the adaptive cycle theory since thy also acknowledge the importance of including as much factors as possible to increase the effectiveness of an element description and understanding.

This final part of the methodology will approach the possibility to have a transfer from Germany to Mexico, regarding decentralized solar energies. With the location of both systems countries in the adaptive cycle as a starting point, the assessment of a possible transfer technology or policy wise will be done emphasizing the preparedness of the host (Mexico) to welcome and be ready to implement the measures that helped the home country (Germany), to be a pioneer in decentralized solar energy.

The possibility to have a negative result is not ignored, since as it was shown in the theoretical framework, if the environment, in this case phase of the adaptive cycle, of Mexico, the host country, is not compatible at all to the measures taken in Germany, or otherwise the measures can’t be adapted to the environment, the transfer at this point of time would be unnecessary since failure would be imminent.

4 Analysis of results

4.1 Conservative energy system Germany

As the following graph shows (Figure 14), Germany has a rather diverse energy mix, having 32.2% as the largest single resource share. There is also another situation that can be identified in the graph that is the dependency of fossil fuels, more than the half of the Total Primary Energy Supply (TPES) is based on oil and coal. Natural gas has an evident big share as well. These resources are going to be analyzed as the three main energy resources in Germany, having, together an 80% share of the TPES.

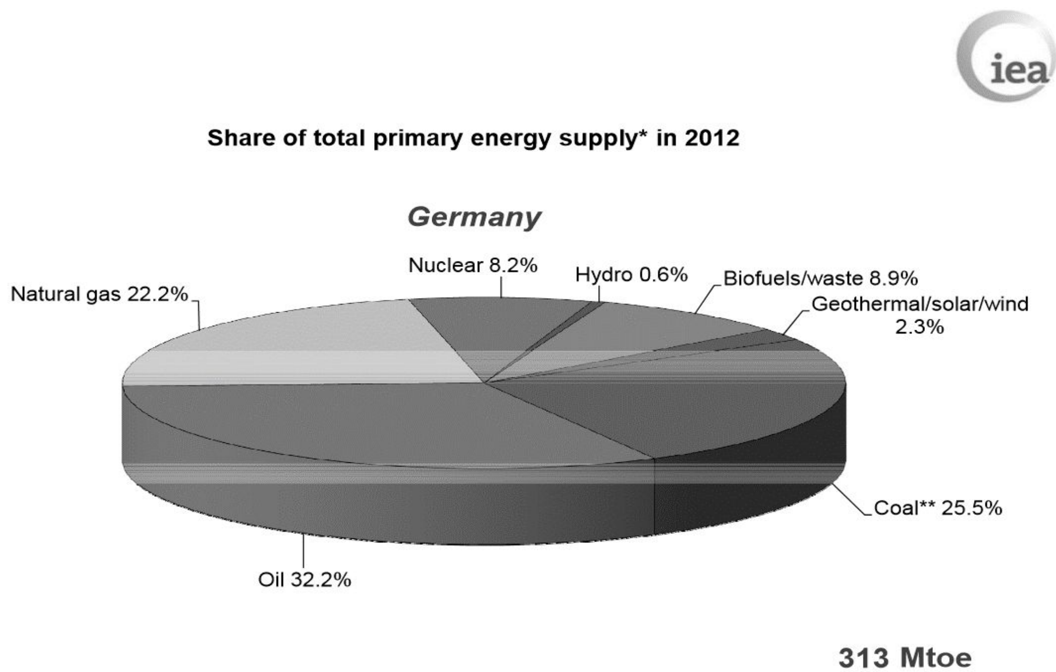

Figure 14 - Share of total primary energy supply in 2012, Germany. Source:(International Energy Agency, 2012a)

4.1.1 Oil

In 1973 Germany relied mostly on fossil fuels to cover its TPES, a 47% to be exact. Although the dominant presence of the fossil fuels in Germany's energy mix is undeniable, it becomes clear how the country has intended an energy generation diversification, compared with 2010's production (International Energy Agency, 2012b), as is shown in Figure 15.

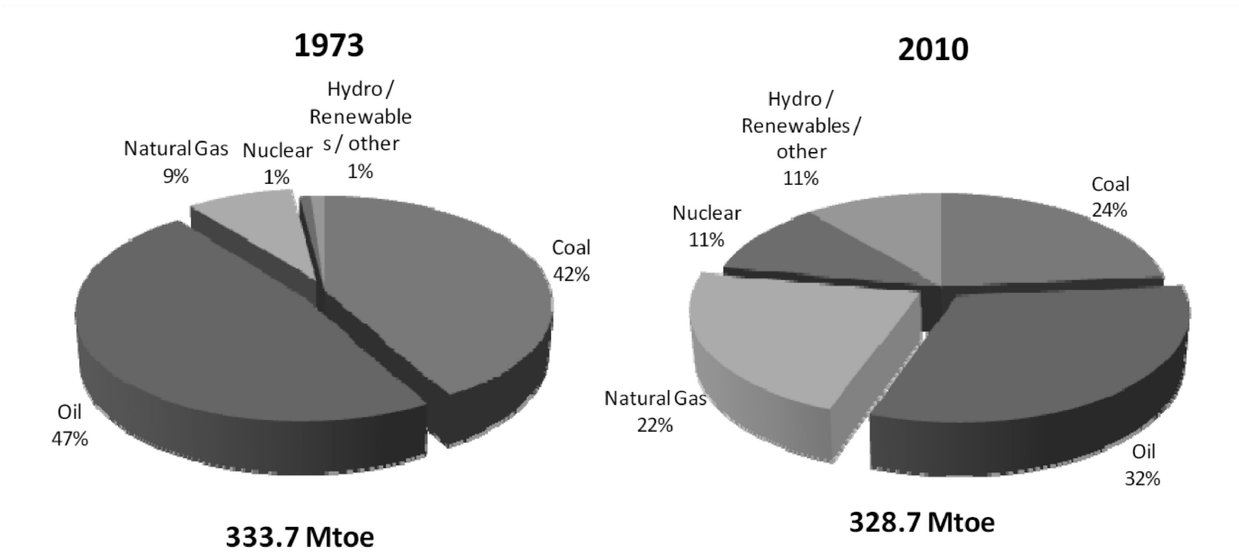

Figure 15 - Total Primary Energy Supply in Germany in 1973 and 2010. Source:(International Energy Agency, 2012b)

Regarding fossil fuels, energy resources in Germany are very limited, having an oil dependency of 96.7% following a growing trend at least until 2018. The main oil exporters selling to Germany are Russia, United Kingdom, Norway, Libya and Nigeria, (International Energy Agency, 2014).

The transportation of the imported oil is made through four cross-border pipelines coming each one from North, West, South and east respectively. Germany also has four main sea ports, with high capacities, after the oil is in the country, it is sent directly to the refineries throughout the county by the domestic pipelines. All the pipelines transport systems are owned and managed by private companies (International Energy Agency, 2014)

In 2012 oil and natural gas represented 32.2% and 22.2% of Germany's TPES (International Energy Agency, 2015c), this represents a high level of reliability on those sources, since they represent more than the half of the energy supply. A strong economy such as the one Germany has, as well as the high quality level, must be prepared in some way in case of a sudden shortage, international tense relationships or other external factor that may endanger the current energy mix resource supply.

One big advantage regarding oil is that it can be easily stored, and when the situation is ideal, there can be an emergency storage to provide it in times of scarcity. Germany has currently 58 storage facilities built into 4 caverns and also 130 above-ground ones, which capacity goes up to 414 mb (International Energy Agency, 2014). The agency in charge of this important storage task is the "German Stockpiling Agency EBV". It is important to mention that Germany planned the size of the storage facilities to fulfill 90 days of oil importations supply (required by the International Energy Agency). There are some different cases, but the cavern facilities storage mostly crude oil while the above-ground facilities storage refined product (International Energy Agency, 2012b).

The main reasons for the EBV agency to release the stocks are following, addressed in the International Energy Agency, 2004's Oil and Gas Security Report:

- *"To prevent an impending, or remove an existing disruption to the supply of energy"*
- *"To counteract a major supply disruption in Germany, or in one or several other EU Member States"*
- *"To meet Germany's obligations with regard to a decision by the IEA Governing Board"*
- *"To provide solidarity support for IEA Member Countries or EU Member States"*
- *"To provide an initial response in a situation of particular urgency"*
- *"To mitigate a local crisis"*

Another important issue regarding the emergency storage is the location, in other words the accurate distribution of the storage facilities to use them efficiently in case of requiring them. In Germany such facilities are well distributed across the country and are immediately available in all market regions (International Energy Agency, 2012b).

Although oil is the leader source of energy in Germany's TPES, it's interesting to acknowledge that it is used in a very small amount to produce electricity, 1.3% in 2012 to be exact. This situation reveals the huge dependence on oil, regarding transport mainly, and how rigid the situation becomes, since currently there are no options to fuel switch this resource, and on top of that, currently there are neither legislations nor polices to enhance a transformation in the system (International Energy Agency, 2014). Currently there isn't any kind of regulation on the oil price in Germany, the prices fluctuate just based in competition. The elements that do get regulated are the fuels used to feed automotive vehicles, gasoline having a 65 euro cents per liter and diesel 47 cents per liter, this is one reason why the German motor industry has been inclined to develop more diesel motor based vehicles (International Energy Agency, 2012b).

The oil sector is totally privatized in Germany, in other words, the German government does not take ownership of any of the oil related companies, and actually many of them, (production, transportation, refinery and retail), are foreign companies like Shell Deutschland, that has the biggest share of the total refineries in Germany (International Energy Agency, 2012b).

The quantity of filling stations all across Germany is declining, both in the normal roads as well as the ones in the autobahns, form a total of 14650 filling stations, the number has reduced to approximately 13050 since 2001, this may indicate a reduction on the usage of oil as a fuel, but when the oil market is observed, it becomes clear that it has been steady for the last years, (International Energy Agency, 2012b), and there have also been a lot of energy efficiency policies regarding energy efficiency in vehicles. (International Energy Agency, 2015b)

4.1.2 Natural Gas

Another huge source of energy in Germany is natural gas, which in 2012 had a 22,2% share in the TPES, being the residential and industrial sectors the most consuming sectors with 31% and 29% respectively from the total demand (72425,46 ktoe) (International Energy Agency, 2015c) (International Energy Agency, 2012b). Natural gas consumption in Germany follows a long term decreasing trend, but at the same time its share within the TPES is expected to keep growing reaching a 24% in 2025 (International Energy Agency, 2014), this situation happens because even though the consumption demand is going to decrease, the importance of natural gas in the TPES matrix is going to rise. These predicted trends are rather unstable because the demand and share in the TPES regarding natural gas depend on a variety of external factors such as the behavior of the nuclear energy demand on the future, the carbon pricing and the possible economic and financial crises (International Energy Agency, 2012b)

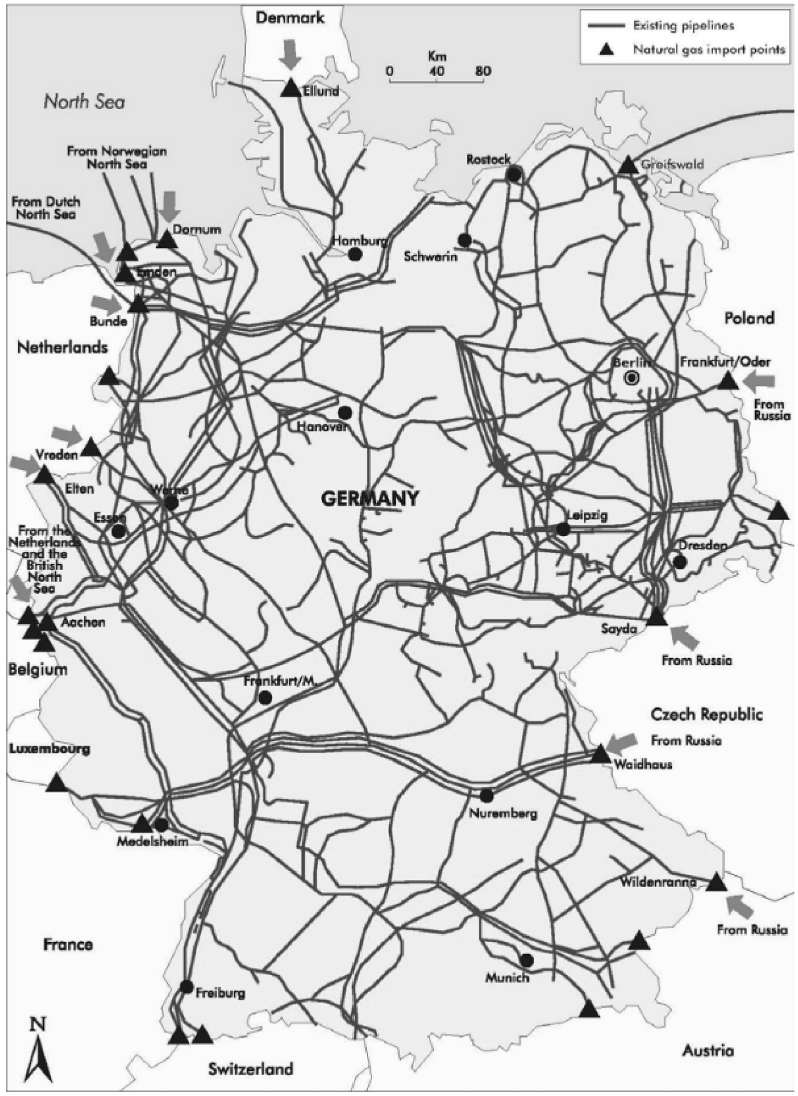

Figure 16 - The Natural Gas Grid in Germany. Source: (International Energy Agency, 2012b)

Natural gas was one of the main "new" resources that from 1973 started reducing the huge majority of the share that oil had in the TPES, growing to a 9% to a 22% in a little less than 40 years. Natural gas as well as oil, has very few reserves in Germany, therefore most of the natural gas demands are imports, almost 86% to be precise, while the local production only takes a 14% share (International Energy Agency, 2012b).

One of the most important elements of an energy generation method or source is the transportation and/or transmission, in the current energy system almost all of the energy consumed either in form of electricity or heat, needs to be transported through massive distances to be delivered to the consumers. There is no exception in the case of the natural gas, considering this important issue; Germany has a diverse list of importers from several locations, mainly Russia Norway and the Netherlands (International Energy Agency, 2012b).

Germany considers natural gas a very good and reliable source of energy, now an in the future, that is why considers very important for its companies to invest in the natural gas transportation system. As in can be seen in Figure 16 the pipelines that get the natural gas form the exporters to Germany and also distribute it all across the country are very efficient, and had a very good impact for the whole European market. Thanks to the central location in reference to the whole continent, Germany has become also a hub for natural gas transportation to other destinations, this also put it in a very good position with the other EU members regarding treaties and diplomacy (International Energy Agency, 2014).

Regarding storage, Germany has neither legislations nor requirements to maintain a stable emergency natural gas stock, not even form international agencies or institutions, however there are 48 gas storage facilities with a total capacity of 20.4 billion cubic meters (bcm), distributed all across the country, where the natural gas is stores in caverns and porous rocks (International Energy Agency, 2014). All of the storage facilities are private owned, but they are obliged to allow other companies the access to the facilities at a fair market price (International Energy Agency, 2012b).

In February 2012, a stressful situation arose, compromising the natural gas situation in Germany. The disturbance that caused this situation was not even a big issue such as political tension, or a massive natural catastrophe, it was only a rather cold winter. When the temperatures dropped below the normal range, south and southeast

Germany increased considerably the demand for natural gas for heating purposes, this lead to a massive reduction in the supplies coming from Russia, the largest supplier, the reaction to this was a quick balance among exporter's supplies trying to satisfy Germany's demand. This situation caused interruption in the contract permitted cases, one of them gas power plants, therefore restrictions on electricity consumption were required (International Energy Agency, 2012b). This situation almost turned into a disaster, but the strong an exceptional natural gas infrastructure that Germany possess allow it to not only pass through it, but also to continue the electricity trade with France while all was happening (International Energy Agency, 2012b). Germany currently meets an N-1 requirement, related to the reliability of the natural gas infrastructure, considering the pipelines double flux quality as well as its accurate distribution across the country (International Energy Agency, 2012b).

Although German infrastructure regarding natural gas is rather reliable, the government does not require the companies to have emergency response measures, it leaves the responsibility of facing a gas scarcity situation to the companies themselves. There are also some measures to face an emergency situation, such as the interruption contracts, and fuel switching equipment. The interruption contracts represents approximately 10% to 20% of the total gas supply contracts (International Energy Agency, 2014). In case of an emergency, the interruption contracts and the companies with fuel switching technologies lose priority to get some of the low supply in that hypothetical situation. The interruption contracts as well as the fuel switching capability are not regulated whatsoever, the government does not have policies or incentives to develop the spread of these emergency practices (International Energy Agency, 2014).

4.1.3 Coal

Coal is a fossil fuel, and unlike oil, the reserves are copious and are widely distributed across the world (IEA Coal Industry Advisory Board, 2013). The coal production is divided in tow main types of the material, lignite and hard coal, which only difference is their calorific value, <6000 kcal/kg is classified as lignite and >6000 kcal/kg as hard coal (Thielemann, Schmidt, & Peter Gerling, 2007). This huge variation among the two types of coal calorific value is mainly due its water concentration of almost 50% in lignite (International Energy Agency, 2013).

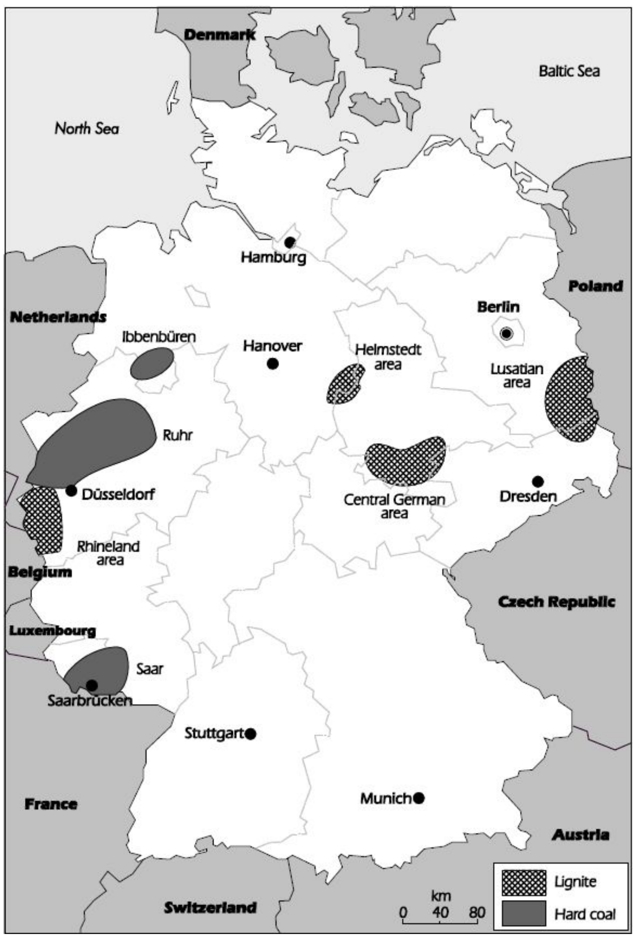

Figure 17 - Coal reserves in Germany. Source:(International Energy Agency, 2013)

Coal represents the 25.5% of Germany's TPES, this makes it the second largest source of energy in the country (International Energy Agency, 2015c). Thanks to the substantial resource reserves that Germany has, coal is the largest domestic conventional fuel (International Energy Agency, 2013).

Although it coal is the largest conventional energy resource Germany has, not all the reserves are homogenous, in 2011 94% of all coal production was the lignite type, having a huge advantage over the hard coal share, it is clear how the demand for hard coal has diminished the last years and the hard coal has rose (International Energy Agency, 2013). This situation happens because of the remaining reserves of each type of coal, while the lignite reserves are still abundant (Figure 17), the hard coal reserves have a deadline to finish extraction by 2018 due high extraction costs and depth (International Energy Agency, 2013).

The coal that is being produced in Germany is being imported and exported, since the demand for coal in the country is biggest than their production, the main activities are the imports, although there are small exports of hard coal, of 1.2 Mtoe in 2012 (International Energy Agency, 2012a). Regarding the lignite, the trade activities such as imports and exports does not play an important role in the behavior of the coal situation in Germany due its great water content and its low calorific value, the lignite is a fuel that is more efficiently utilized domestically (International Energy Agency, 2013).

Germany supplied almost 80 Mtoe of coal in 2011; a huge diminishment from the mid 80’s where the supply reached 140 Mtoe. Currently from that supply, the huge majority, more than 50% is destined to power generation plants, making the most used resource in terms of electricity generation, and considering the coal production is highly ruled by lignite, is accurate to say that lignite is the main fuel to generate power (International Energy Agency, 2013).

There has only been one coal producer in Germany, RAG AG, this company has suffered restructuration since 2007 when the decision to stop producing coal was made, some shareholders sold their shares to British investors , remaining at the end the RAG foundation as an owner and main responsible for the hard coal “phase-out”. The company should have a specific amount of money to fulfill successfully the goal to stop production, it will require 13 billion Euros in 2019 to do so, and if the needed amount money is not reached the states where the mines are and the government will give the required money to complete the responsibilities (International Energy Agency, 2013).

The main attributes that the lignite has are the security it provides as an energy generation resource and its good affordability compared with the other sources of energy. It is also versatile, since it is used to produce several variations of coal such as briquettes pulverized coal and coke (International Energy Agency, 2013). Lignite mining an production is located widely across Germany due its distribution (Figure 17), having in 2012 a total of twelve mines owned and operated by 5 main companies in the regions of Rhineland, Helmstedt, Lausitz and Central Germany. All the mines excepting the one in Helmstedt and one in Central Germany, own their own power plants, controlling this way almost the whole process, from extraction to energy production for the consumers (International Energy Agency, 2013).

The government is involved in the coal production being that provides subsidies to the hard coal production specifically. North Rhine-Westphalia and the federal government agreed on providing subsidies to the coal extraction industry due its great employee capacity, but it was in 2010 when the European commission proposed to stop the help from the government by 2014, which later was extended to supposedly end by 2018 cause of dislikes and resistance from the people, since the extraction industry itself has more than 40000 employees (International Energy Agency, 2013).

Germany has abundant lignite reserves which are a very viable source to provide flexibility to the energy system. The coal production trend has been rather stable the last years and it appears to be going to continue since the proved reserves of the resource in Germany are approximately 41 billion ton, Which are easily sufficient to maintain the production for 200 years more. (Thielemann et al., 2007) (International Energy Agency, 2013)

Table 2 - Conservative Energy System (Germany), Indicators Assessment. Source: Own elaboration.

Conservative Energy System (Germany)			
Resistance	Diversity	Tolerable	Even though renewable energies are pushed every year towards impressive goals, this only represents a part of the energy consumption of the country, only electricity production to be exact, the lack of policies, legislation and government budget to invest on research and development for fuel switching, shows that there are really no option for the biggest energy sources in Germany's TPES.

	Synergy	Very Good	The system is very well adjusted, and all the elements work together impressively efficient to overcome with disturbances that may cause an energy shortage, fixing the problem immediately using all the resources possible, one example is the natural gas situation in 2012.
Adaptability	Dynamicity	Very Good	A rather strong infrastructure allows the system to form different configurations if required to fulfill the required demand. Energy distribution lines and power plants are distributed in all the country so they can be at some degree independent from each other, also getting help from the emergency storage programs.
	Learning	Very Good	The system is highly capable to learn from situations, for example again, the Natural gas Incident in 2012, was a milestone to develop new technology for infrastructure an also a guide to develop policies that in the future are going to be able to deal with such situations
Transformability	Preparedness	Tolerable	The system is clearly getting feedback from the disturbances happening but only from the economic-financial system, implementing it in policy making and R&D, but everything inside the same

			fossil fuel scheme, the system is prepared to face almost any disturbance that does not compromise the reliance on fossil fuels. Although improbable a situation where fossil fuels cannot be used the system would hopelessly collapse.
	Innovation	Good	Even though the system trend is based on the fossil fuel dependency, the system does embrace innovation, not at a degree of fuel switching, but technology is rapidly developing specially on energy efficiency matters, trying to obtain more energy from the same amount of fuel.

4.2 Decentralized solar energy system Germany

Even though in the TPES the solar energy does not have a large share (2.3% together with wind) (International Energy Agency, 2012a), the share of electric energy Is very impressive, having 12.5% of total energy consumption and 20.3% of gross electricity consumption (Mundo Hernández et al., 2014). In 2011 Germany was the third country to invest in Renewable energies development (EUR 22.9 billion), just below China and United States (International Energy Agency, 2013), which is a great accomplishment considering the differences among territory size and population.

Germany has also set impressive goals to fulfill until 2050 when the share of renewables in the German power supply is supposed to reach an 80%. In 2011 PV solar energy installed capacity was 25 039 MW producing 22.2 TWh, which is expected to double by 2020 (International Energy Agency, 2013).

One of the main policies promoting decentralized solar energy systems is the “renewable Energies Act” amended in 2011, which supports the idea of low scale solar energy applications, and not only electricity generation related, but also for heating/cooling. This act states that all the new buildings, residential or business, must have a portion of their heating/cooling necessities, covered with renewable energies (solar thermal, biomass or geothermal). This measure gives the liberty to the consumer/producer to choose among the best suitable option. This act is not retroactive excepting the public owned buildings that are obliged to follow the it even though they were built before its amendment (International Energy Agency, 2013).

The policy making in Germany regarding the support of solar energy production is mainly based in the following aspects collected from IEA (International Energy Agency, 2015a):

- Economic instruments and financial incentives such as loans, grants, subsidies, tax reliefs and Feed-in tariffs.
- Regulatory instruments and mandatory requirements.
- Voluntary approaches.
- Negotiated agreements between public and private sectors.
- Research, Development and Deployment (RD&D).
- Technology diffusion.

Germany is slowly breaking the model of “Success to the Successful” (Dangerman & Schellnhuber, 2013) in the market of photovoltaic systems, since the prices for both energy produced and equipment are dropping and it is projected they are going to continue dropping over medium term (International Energy Agency, 2013).

Solar PV production helped throughout the “cold snap” in February 2012, being able to maintain the export to France even in the highest peaks (International Energy Agency, 2013). This shows a great degree of connectedness to the conservative energy system and also proves that is a reliable source of energy, possibly not as reliable as fossil fuels, but nevertheless it was available in emergency.

The relatively recent success of the solar energy implementation in Germany is due the high governmental and institutional support to make accurate policies to reach the set goals (International Energy Agency, 2013).

Table 3 - Decentralized Solar Energy System (Germany). Indicators Assessment. Source: Own Elaboration.

Decentralized Solar Energy System (Germany)			
Resistance	Diversity	Tolerable	Although the technology is being implemented more and more, the solar technology still does not have the development or the level of evolution to fulfill all the energy requirements that the fossil fuels do. Currently the real main uses for solar irradiation are Thermal and electricity generation through PV. The increasing of the share in the energy production makes solar energy necessary, and it is getting harder to replace as that share grows.
	Synergy	Good	The system is fast growing to reach impressive shares of the total production; this situation can easily be explained through the great functioning among the key actors, such as government, private companies, market, economy, and community. It is true that the system has not reach yet its conservation peak; it is certainly true that it is on

			its way there.
Adaptability	Dynamicity	Tolerable	There are a lot of incentives and mandatory measures to incite the population to become small scale solar energy producers, most of those systems are connected to the grid, which are not necessarily independent from the transmission systems, but a definitely advantage is the wide usage of solar heaters, which are systems that are independent from big networks or other large systems.
	Learning	Good	Even though the system is still in development, the accurate policy making and the fast growing and accumulation of potential shows a clear capacity to learn from successful and failure experiences.
Transformability	Preparedness	Good	As it happened in the “cold snap”, where there was a shortage in a main energy source, all the other sources and infrastructure helped to pass through it, with this logic, the decentralized solar system, which represents a much lower share of the energy mix, would be relatively easy fulfilled while the disturbance is solved.
	Innovation	Very good	The system is totally open for innovation to increase the solar

			energy production, specially to RD&D to increase the efficiency of the equipment (International Energy Agency, 2013).

4.3 Conservative energy system Mexico

As Figure 18 shows, there is a huge dominance on Mexico's TPES by oil and natural gas, holding more than the 84% of the total 188 Mtoe. It is clear how these resources are the leaders in energy supply in Mexico, for that reason they will be analyzed further.

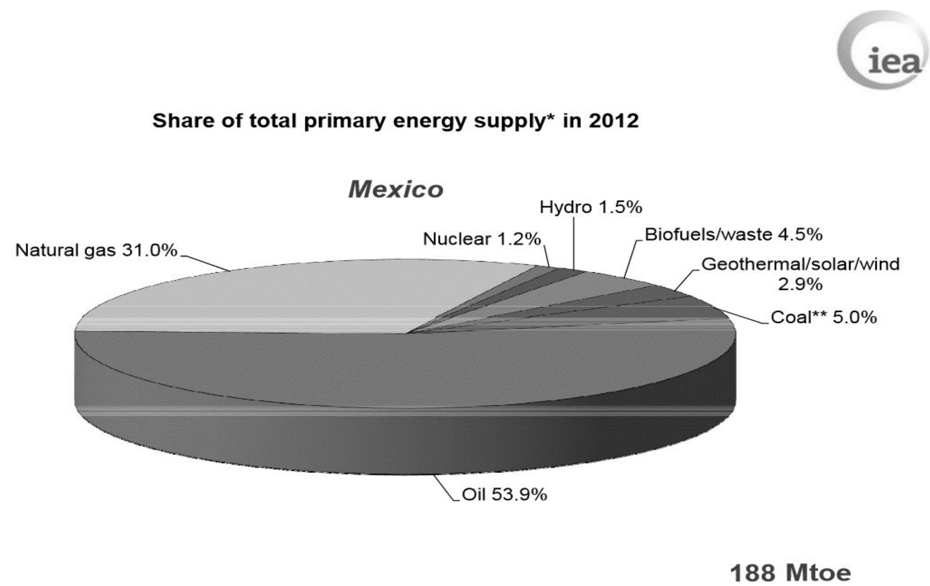

Figure 18 - Share of total primary energy supply in 2012, Mexico. Source: (International Energy Agency, 2015d)

4.3.1 Oil

The discussion about oil in Mexico has always been quite brittle since it is the main source of energy in the TPES, and represents the 6.1% of the GDP.

Mexico has considerably good oil production and reserves, therefore is the 10th oil producer in the world, producing 393.68 Ktoe daily (International Energy Agency, 2015d).

In 1938, Mexican President Lazaro Cardenas issued a decree to expropriate all the fossil fuels from the foreign and private companies, giving the state the only power to drill, produce, refine and sell all the oil resources, creating "PEMEX" (Mexican Petroleum). The company has had high and lows throughout the years and various administrations, but it has consolidated as a strong oil production company, ranking as the 7th largest oil company worldwide (PEMEX, 2015a),(Alemán-Nava et al., 2014)

Even though oil reserves provides information about the resources still available in the country, it's a bit complicated to understand fully what such quantity may need, that is why three types of reserves: possible, probable and proven. The main differences among these types of reserves is their degree of feasibility, obtain through multidiscipline studies, being that the proven reserves are the most representative data in a short term future, since they represent the reserves have sufficient economy, finance, geographical, and social feasibility studies to back them up as reliable (Pemex, 2013).

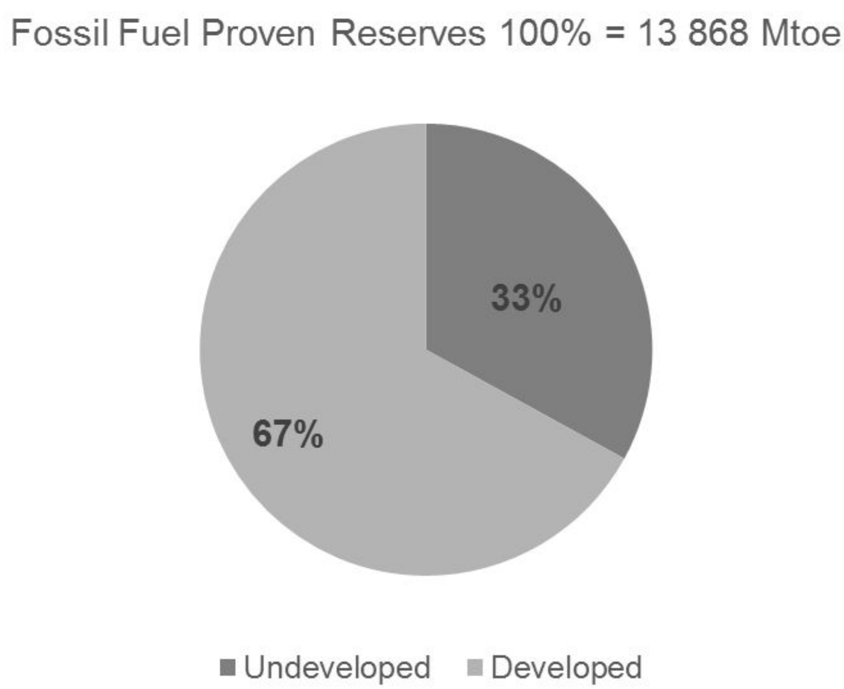

Figure 19 - Fossil Fuel Reserves in Mexico. Source: Modified from (Pemex, 2013)

Currently Mexico has a total oil reserves amount of 4 314 Mtoe, but only 1 410.22 Mtoe represent the proven reserves (Pemex, 2013) , this represents approximately one third of the total reserves, with the help of a bigger R&D budget this radio could increase towards the proven reserves. Regarding the proven reserves, there are two more subcategories, the developed reserves and the undeveloped reserves; this proven reserves status depends on the necessity of brand new infrastructure to exploit them. The developed reserves are the ones that can easily be exploited with the current infrastructure and with the current drilled wells while the undeveloped require a new investment to do so (Pemex, 2013). As it is shown in Figure 19, from the fossil fuels proved reserves total, the majority are developed, while near one third are still considered as undeveloped.

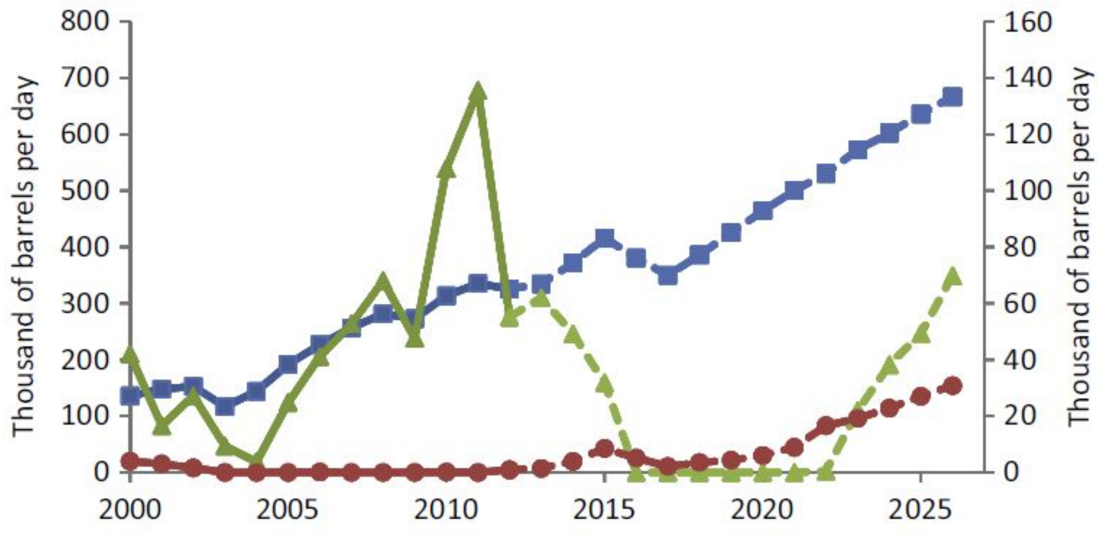

Figure 20 - Thousands of barrels imported a day in Mexico. Source: (Alemán-Nava et al., 2014)

Oil production represents a huge part in Mexico's economy, it contributes to the GDP in a considerable percentage, it represents 8% of the total exports of the country, besides this situation, the astonishing 56% of the public investment is aimed to develop energy projects and analyzing the energy mix of the TPES, apparently not enough has been invested on decentralized renewables (Alemán-Nava et al., 2014). Mexico also has a strong taxation system regarding oil, since all the taxes related in one or other way to oil represent a 37% share of the total federal budget. Oil industry plays an important role in the employment sector in Mexico, since only oil companies provide employment to more than 250 000 people (Alemán-Nava et al., 2014), this clearly shows a high economy dependency to oil.

The importance of oil production in almost every aspect of the functioning of Mexico as a country is undeniable, nevertheless oil production has decreased, due the exhaustion of the current active wells (Alemán-Nava et al., 2014), and as it was mentioned before, the proven reserves are not enough to maintain the production rate.

Almost ignoring the enviable renewable potential Mexico has, the strategies to overcome this possible fossil fuel shortage are mainly increase considerably the imports of refined fossil fuels based on a 2026 projection, (Figure 20), and the implementation of the new energy reform, which the government is actively pushing since 2013. The reform consists mainly of fomenting and encouraging the increase of the proven reserves and, therefore the fossil fuels production, all of this through opening the oil production and exploration to foreign companies for the first time in the history of PEMEX. (H. Congreso de los Estados Unidos Mexicanos, 2014),(Alemán-Nava et al., 2014)

4.3.2 Natural Gas

This resource is the second most important in Mexico's TPES, accounts the 31% of the whole production (International Energy Agency, 2015d). Natural gas is in a similar situation as oil regarding the reserves, there is a considerable amount of the resource available, but is divided in three types of reserves as well.

The proven reserves of natural gas in Mexico reached the 444.6 Mtoe (Pemex, 2013), a decent amount considering that the share of the TPES in 2012 was 58.28 Mtoe (International Energy Agency, 2015d). The possible reserves more than triples the proven reserves accounting a total of 1 643.2 Mtoe, which gives Mexico an option to give more budget to R&D and increase the proven reserves.

Until 1995 the transportation, distribution and retail of natural gas in Mexico was held only by Mexican companies, after this date the law regarding natural gas activities was reformed and then the market of this end of the process activities was open for private and foreign companies, all of this in order to increase competitiveness. All of the contracts and regulations are coordinated by the CRE, (PEMEX, 2015b), (Sener, 2013).

There is a network of pipelines in Mexico for transportation purposes, but assessing the map of such pipelines is clear how most of them are designed for exportation purposes, since the main ends of the pipes are located in the northern border and also near from the main seaports, (Sener, 2013) . In some parts of the country the transportation of gas in tanks for its residential use is still a valid distribution means.

Figure 21 - Natural Gas pipes and pumping stations distribution in Mexico 2012. Source: (Sener, 2013)

The natural gas distribution and transportation infrastructure in Mexico is predicted to grow, since a lot of cross-state projects are being supported by the government (Sener, 2013).

The demand of natural gas is increasing, since all the factors triggering this situation are considered to do it at least until 2027. These factors are the increase of infrastructure, the population growth, the necessity to increase exports to help the GDP percentage rise (Sener, 2013).

In 2013, Mexico had a total of accumulated reserves from both oil and natural gas, to fulfill the current production for 10.2 years, with only the proven reserves. If the possible reserves are taken into account the quantity would triple, being 32.9 years of fossil fuels supply (Pemex, 2013). The previous data makes evident the necessity to invest on R&D to increase the proven reserves, in case the current energy system is to be maintained.

The Department of Energy in Mexico (SENER), has as one the main strategies to overcome with a possible shortage situation to increase the efficiency in all the fossil fuels applications processes (Mundo Hernández et al., 2014).

Table 4 - Conservative Energy System (Mexico). Indicators Assessment. Source: Own elaboration.

Conservative Energy System (Mexico)			
Resistance	Diversity	Good	Even though the renewable energy development has not reach a considerable place in the share of energy, the county still have options in case of a disturbance, this option is the huge potential for renewables and also the amount of fossil fuels possible reserves, in other words, the reserves that are still not exploited or assessed for feasibility.
	Synergy	Good	The system is mainly based in fossil fuels, an though it has some flaws in infrastructure and it is still developing the infrastructure to have an effective distribution, the TPES production has been able to keep maintaining its share of the GDP and being an important factor in the economy, also providing 95% of the population with electricity, the highest percentage in Latin America (Alemán-Nava et al., 2014)
Adaptability	Dynamicity	Tolerable	The system can stay the way it is functioning having more than 85%

			of the TPES based on fossil fuels for furthermore years, but the reserves can only replace the lack of dynamicity for a certain amount of time, the system needs to diversify regarding the energy mix and also to increase infrastructure in order to be able to create a larger number of rearrangements to be able to supply the demand.
	Learning	Tolerable	The fossil fuel production in Mexico is a milestone in the development of the country and it is deeply related with the Economical-financial and policy systems, but not very much connected with the environmental one, since most of the new energy reform only focuses on the increasing of the fossil fuels production. Nevertheless the system does learn, not very fast, but for example it's aware of the reserves left, and the need of increasing efficiency, directing the policies towards those goals.
Transformability	Preparedness	Tolerable	The system is in a good position in regards of this indicator, since the abundant fossil reserves the country possesses allows it to overcome to any disturbance related to shortage, the only issue with this advantage is

			the lack of infrastructure to access rapidly to the reserves, since approximately only one third of the total possible reserves are proven. In the same case as Germany, in a situation of a disturbance which stops totally the production or availability of fossil fuels, the system is not prepared at all, it undoubtedly collapse beyond repair.
	Innovation	Poor	Possibly the amount of reserves gives the country a sense of confidence, but the truth is that it is not open to innovation, since the “new” measures recently taken to develop the country’s energy sector all are based on increasing oil and gas production, increasing efficiency and increase imports, all of them making the system even more dependent on fossil fuels.

4.4 Decentralized solar energy system Mexico

Mexico has an extremely good position for solar energy generation, receiving between 6.13 and 5.66 KWh/m^2 daily in most of its territory (Mundo Hernández et al., 2014), which represents a possible potential generation of 6 500 000 GWh/y (SENER Secretaria de Energia, 2015), enough to cover the complete energy demand at a 2 189.40 % (Hern, 2014). It is not realistic to take into account the possible potential, since this term represents just a theoretical approximation of it, that is why a more accurate quantity is going to be used, that is the proved generation potential which is 8171 GWh/y (SENER Secretaria de Energia, 2015), this may seem disappointing considering the previous possible amount, but it is important to make clear that it is called "possible" because there is not enough R&D in that topic, otherwise the proved potential would rise.

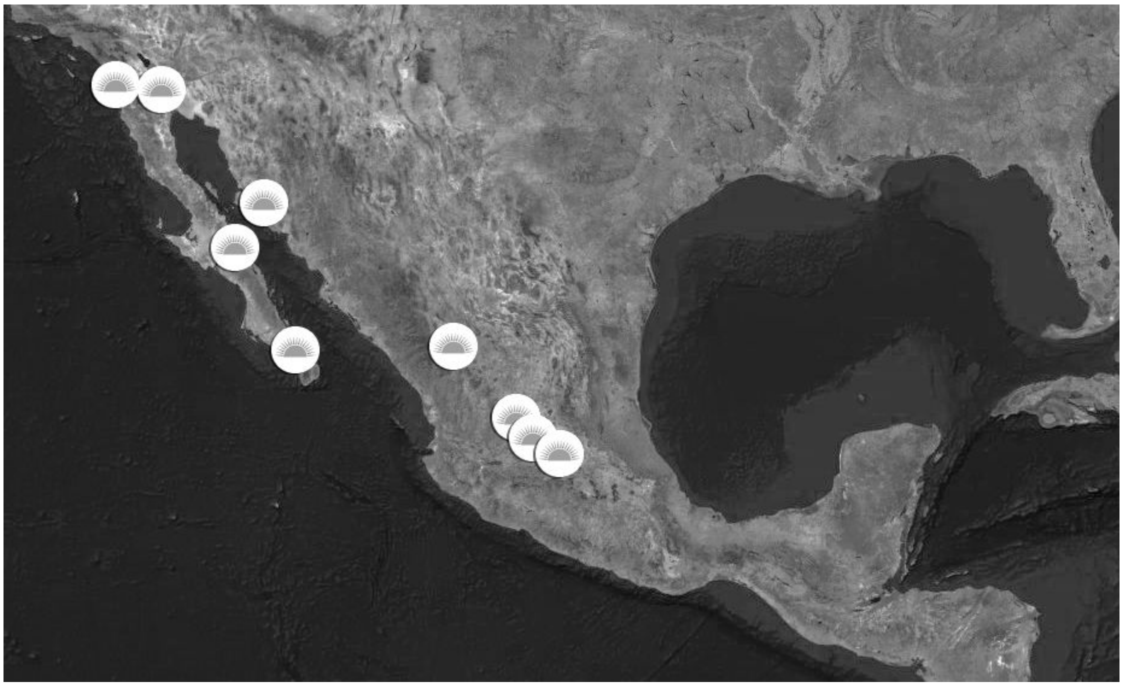

Figure 22 - Mexico Large Scale PV Plants. Source:(SENER Secretaria de Energia, 2015)

Although Mexico has an enviable position regarding sun irradiance, there are only nine photovoltaic generation plants (Figure 22); two of them are federal owned while the remaining seven are private. The solar plants are distributed all across the country revealing where the irradiation "hot spots" are, as is shown is Figure 23. There is currently no information regarding solar thermal energy production plants in Mexico (SENER Secretaria de Energia, 2015), it is inferred there are still no installation to exploit this kind of technology. The largest plant has a size of 38.75 MW, all of them put together a total installed capacity of 66.21 MW and an approximately generation of 84 GWh/y (SENER Secretaria de Energia, 2015). The total generation of electricity through photovoltaic technology is barely a .01% from the total production, not even dealing with TPES; this percentage is extremely small considering the possible and proved potentials.

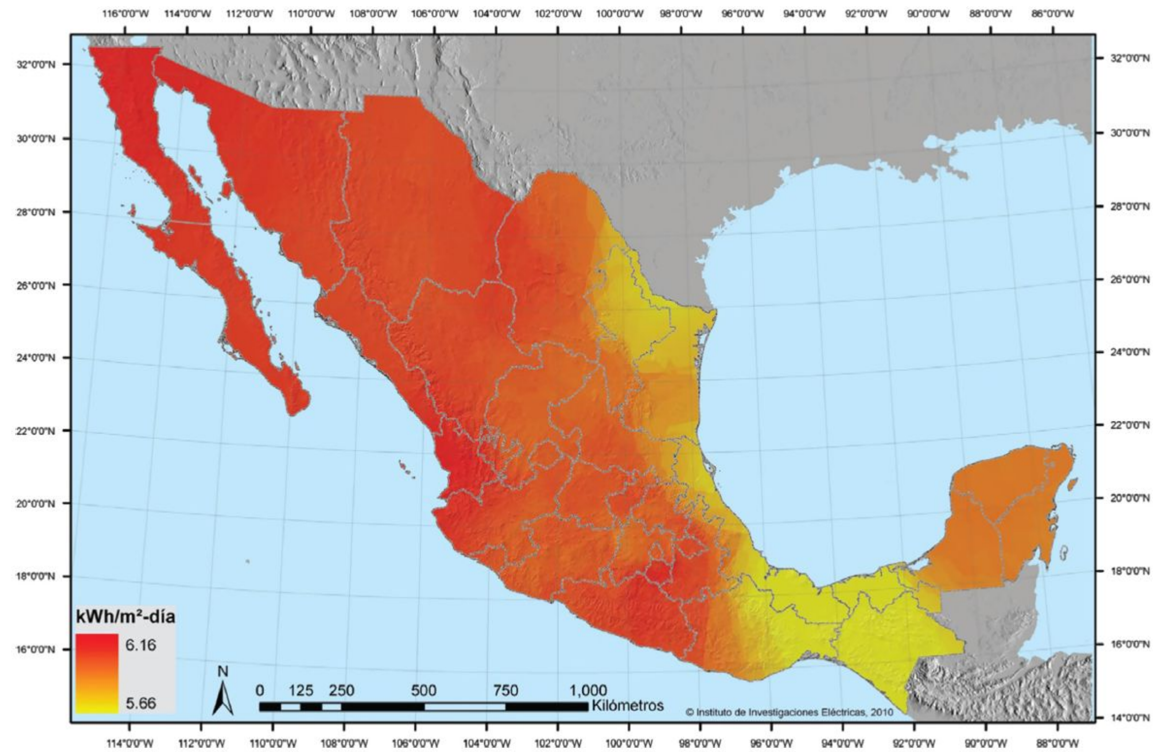

Fig. 5. Mexico's average solar radiation distribution (Instituto de Investigaciones Eléctricas & SENER. Available from: http://sener.gob.mx/webSener/res/1803/Solar.pdf [accessed 18.09.13]).

Figure 23 - Mexico's average solar radiation distribution. Source: (Mundo Hernández et al., 2014)

The previous data provided in the previous part indicates the production of energy through photovoltaic as well as their share in the electricity generation, but only coming from what the Mexican government considers as large size plants, the medium and small scale generation systems are not considered in that calculation.

The electricity in Mexico was completely private until 1933 when it was stated that the electricity generation industry is a public profit activity. Due the high prices that arose from the private companies that only considered urban consumers to provide electricity, the government created a federal electricity commission, which target was to provide energy to the whole country no matter the social status, since at that time 62% of the population lived in rural locations. The commission grows at a very high speed as well as the development of the country, but it was until 2009 that it consolidated as the only company to provide electricity in the Mexico. Currently Mexico is provided with electricity by that federal company, CFE (Comision Federal de Electricidad), this company is the only responsible for the generation, transmission and retail of electricity.(CFE Comision Federal de Electricidad, 2014). Is important to highlight that CFE is a massive industry and business, it is the 6th largest power company in the word (Alemán-Nava et al., 2014).

CFE created in 2001 a Net-metering system, leaded to small producers to be able to connect their decentralized solar system to the grid. There is one size restraint for a system to be considered in the contract, it has to have a maximum capacity of 500KW, it also provides some benefits such as a priority over other types of generation such as fossil fuels, and 50% to 70% transmission and connection costs. (CRE Comision Reguladora de Energia Mexico, 2013). Following the net metering definition it also allows to “Record and calculate the difference between the power delivered by the generator to the grid and the energy delivered by the utility to develop consumption bill” (CRE Comision Reguladora de Energia Mexico, 2013).

In 2014 the total amount of medium and small scale net metering contracts in Mexico was 61 896, adding a total of 58.24 MW capacity and 50.4 GWh/y generation (CRE Comision Reguladora de Energia Mexico, 2014), this is almost the same capacity as the installed large plants. There is no information about communities based projects in Mexico.

By law, Any person can own a private decentralized solar system without connecting it to the grid, therefore battery based mainly, since there is no regulation about owning these kind of systems there is no way to know how much capacity they represent.

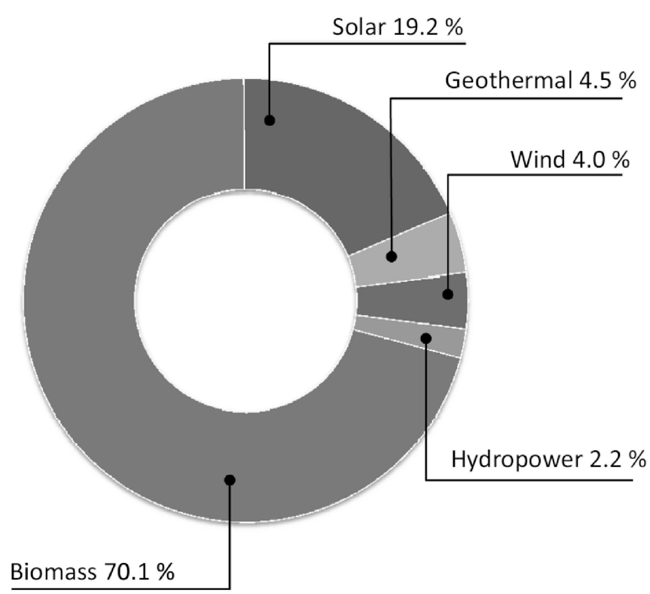

Figure 24 - Research effort of renewable energy sources in Mexico from 1982–2012. Source:(Alemán-Nava et al., 2014)

Regarding solar thermal technology, Mexico has a small application in the field; it is comparable to the standalone PV systems situation, since a solar heater is a private property without regulations, there is still no statistics about the power savings nor usage. Nevertheless a program in Mexico is being pushed by the national workers housing fund institute (INFONAVIT, Instituto del Fondo Nacional de la Vivienda para los Trabajadores), which features housing credits with solar heaters included in a large scale time credit, mitigating the economic blow that this kind of investment represent (Infonavit, 2015).

The domestic capacity of energy in Mexico from solar PV systems is almost the same as the generated by the large scale projects (58.24 MW (CRE)). It appears to be a good indicator of people involvement in the local and own energy generation, but having a look into the quantity of individual contracts given until 2014, around 9000 (CRE), show that the average PV system size is approximately 6KW. Analyzing the data it can be inferred that, although there are people involvement in the energy generation, there is no community cohesion, people who dare to install a PV system do it for their own consumption, there appears to be no community based contracts or projects.

In 2014 energy and research institutions in Mexico (FSE, SENER and CONACYT) provided 27.7 Million USD 2015 to the construction of a New Mexican Renewable Energies Innovation Centre, specialized in solar energy (Ruiz Jaimes, 2014).

19.2 % of the paper published between 1982 and 2012 in Mexican Universities were about solar energy, this statement is based in a study where only the Scopus database was used to find articles (Alemán-Nava et al., 2014). Although this may look as a random indicator, it shows a trend, what are the main sources, people thinks needs research since it influenced them to choose the topic, the complete share graphic Figure 24 shows how the biomass related published scientific articles are widely dominant.

4.4.1 Case Overview: Decentralized Solar Public Lighting System in SLP, Mexico.

An overview of a specific background case in the city of San Luis Potosi was put together from the information found in the available resources, the city news.

One of the main streets in San Luis Potosi is called "Boulevard Rio Santiago", the public lighting is very necessary in this place due its dark environment. Since its construction, it has been prone to get flooded in the rain season, there were also problems due the frequent cupper cable stealing due the poor security in the area (Plano Informativo, 2010).

In 2010 Boulevard Rio Santiago suffered from a big flood which affected and made damages to the subterranean public lighting cable system, causing an almost total blackout, leaving 85% of the public lighting without service, this situation was quite severe. The Urban Management Director, Eduardo Espinosa, pointed that the solution to this problem would be the installation of PV street lighting systems to be installed in the next four years(Plano Informativo, 2010).

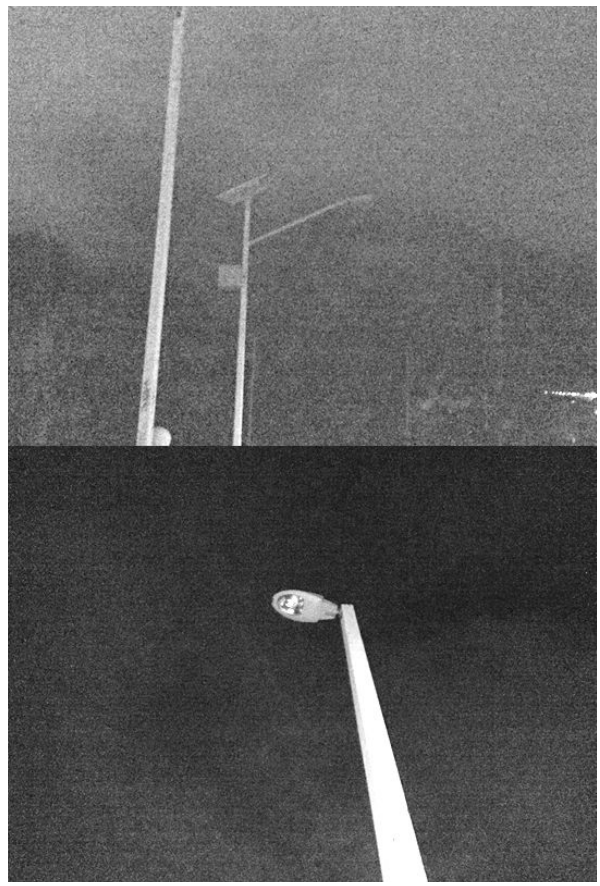

Figure 25 - Condition of the decentralized solar public lighting system in SLP. Source: Own elaboration.

It was until 2012 when part of Boulevard Rio Santiago was provided with photovoltaic public lighting systems as a pilot project, working properly in its recent installation (El portal SLP, 2012), but in 2014 when the place was visited to do an observation of the equipment, several flaws were detected, such as bad maintenance, several equipment without service, and the poles paint is in very bad shape, exposing them to rust (Figure 25).

Table 5 - Decentralized Solar Energy System (Mexico). Indicators Assessment. Source: Own elaboration.

Decentralized Solar Energy System (Mexico)			
Resistance	Diversity	Very Good	The technology has a practically exhaustive source of energy, and since the share of the total energy production is tiny, in case of a disturbance, has a lot of options to turn around to fulfill the possible temporal lack of supply.
	Synergy	Poor	To own a solar system represents an inversion that many people are not able to make, therefore prefer other options. Lack of knowledge about the technology also stops the people to get involved with the technology; nevertheless there are few attempts to involve all the elements together like the housing solar heaters proposal and the net-metering policies.
Adaptability	Dynamicity	Tolerable	Decentralized solar energy systems have a huge potential to be dynamic and become independent standalone systems, but the current situation shows that most of the cases, the infrastructure from other system is required to be able to use the energy produced. Only the installed batteries based systems are almost perfect regarding this

			indicator.
	Learning	Tolerable	Since the technology behind solar energy production is relatively simpler than other energy sources, the system has not yet faced problems to learn from like being responsible for GHG and CO_2 emissions; their only learning opportunity is to increase efficiency in the equipment.
Transformability	Preparedness	Very poor	The systems sometimes are not working and even though there are failures because of several reasons, they may never get fixed like the case in San Luis Potosi.
	Innovation	Very good	The system is completely open to new technologies that can help improve the energy production through solar technology.

4.5 Systems phases in the adaptive cycle

Most of the resilience indicators in the conservative energy system in Germany point to a very resilient system; it is highly adaptable to disturbances and also learns fast and effectively from experiences. The elements of the system are deeply connected to produce energy even in emergency cases. These are the characteristics of a late conservation phase in the adaptive cycle but since the resilience is also high, the system is probably in a rigidity trap, where most of the energy system relies on fossil fuels that the country cannot produce domestically.

The decentralized solar energy development in Germany is already organized as an alternative source of energy, and although the energy production still does not compete against the big shares of fossil fuels in the TPES, the policies and efforts from all organizational levels are encouraging the fast development of the technology, therefore the system is located in an early exploitation phase, where the technology is already consolidated as a part of the TPES but not reached a phase of conservation yet.

The previous analysis shows how the conservative energy system in Mexico has been organized and exploited for a long time, even getting into a healthy conservation phase where the potential (Infrastructure, reserves and knowledge), still has time and space to accumulate and allow the system to grow. Nevertheless it is important to highlight that the system is following the trend of a system which is going to a late conservation phase and possibly into a rigidity trap due its low diversity on energy generation.

The decentralized solar energy system in Mexico is clearly a good option to do an energy transition, but the analysis shows how this technology has been underdeveloped and still has not very much connectedness among the main actors such as institutions, private companies and community. This situation shows the system's lack of a strong assembling; therefore it is located in the organization phase within the adaptive cycle.

Figure 26 shows the location of the analyzed energy system within the adaptive cycle.

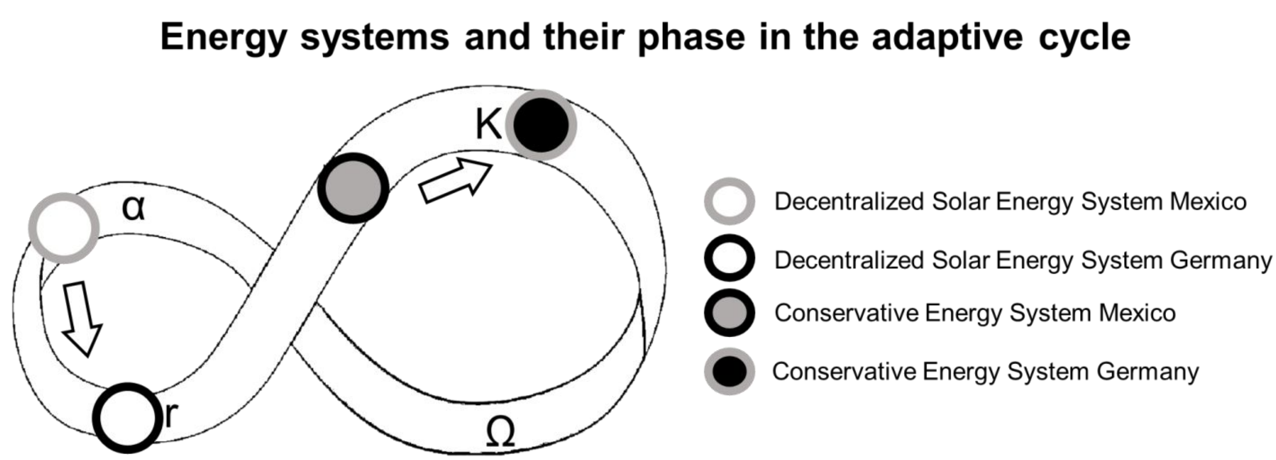

Figure 26 - Identification of the energy systems within the adaptive cycle. Source: Own elaboration.

4.6 Key countries indicators

Table 6 - Key Indicators, Mexico. Source: Own elaboration.

Parameter	*Year*	*Value*	*Sources*
Population (millions)	2012	117.05	(International Energy Agency, 2015d)
Gross domestic product (GDP)(billion USD)	2012	1027.51	(International Energy Agency, 2015d)
GDP per capita (USD)	2012	9819.5	(The World Bank, 2015a)
Energy production, primary (MToe)	2012	218.98	(International Energy Agency, 2015d)
Net Imports (MToe)	2012	-22.89	(International Energy Agency, 2015d)
TPES/population (toe/capita)	2012	1.6	(International Energy Agency, 2015d)
Urban population (%)	2012	78	(The World Bank, 2015a)
CO_2 emission estimates (Mt of CO_2)	2012	435.79	(International Energy Agency, 2015d)
Electricity consumption per capita (MWh)	2012	2.10	(International Energy Agency, 2015d)

Table 7- Key Indicators, Germany. Source: Own elaboration.

Parameter	*Year*	*Value*	*Sources*
Population (millions)	2012	81,92	(International Energy Agency, 2015d)
Gross domestic product (GDP)(billion USD)	2012	3073.86	(International Energy Agency, 2015d)
GDP per capita (USD)	2012	43931.7	(The World Bank, 2015a)
Energy production, primary (MToe)	2012	123.38	(International Energy Agency, 2015d)
Net Imports (MToe)	2012	199.56	(International Energy Agency, 2015d)
TPES/population (toe/capita)	2012	3.82	(International Energy Agency, 2015d)
Urban population (%)	2012	75	(The World Bank, 2015a)
CO_2 emission estimates (Mt of CO_2)	2012	755.27	(International Energy Agency, 2015d)
Electricity consumption per capita (MWh)	2012	7.14	(International Energy Agency, 2015d)

5 Discussion

Dangerman & Schellnhuber, (2013), proposed the analysis of the energy systems as a complex system relation using the concepts of adaptive cycles and panarchy. They portrayed the energy generation panarchy using two different adaptive cycles to describe the conservative and the alternative or renewable based systems. This thesis addressed the analysis the same way, separating the fossil fuel based system from the decentralized solar one in this case, but the truth is that when the time came to make the resilience analysis of the systems through the indicators matrix (Riveros Ospina, 2013), it was very hard to try and describe each one of their adaptive characteristics as separate systems, since both have the same goal in the same time span:, to provide energy. The behavior of the systems is codependent, there is one single system, as it is shown in Figure 27, both kinds of energy production and supports each other in case of disturbances, increasing the resilience.

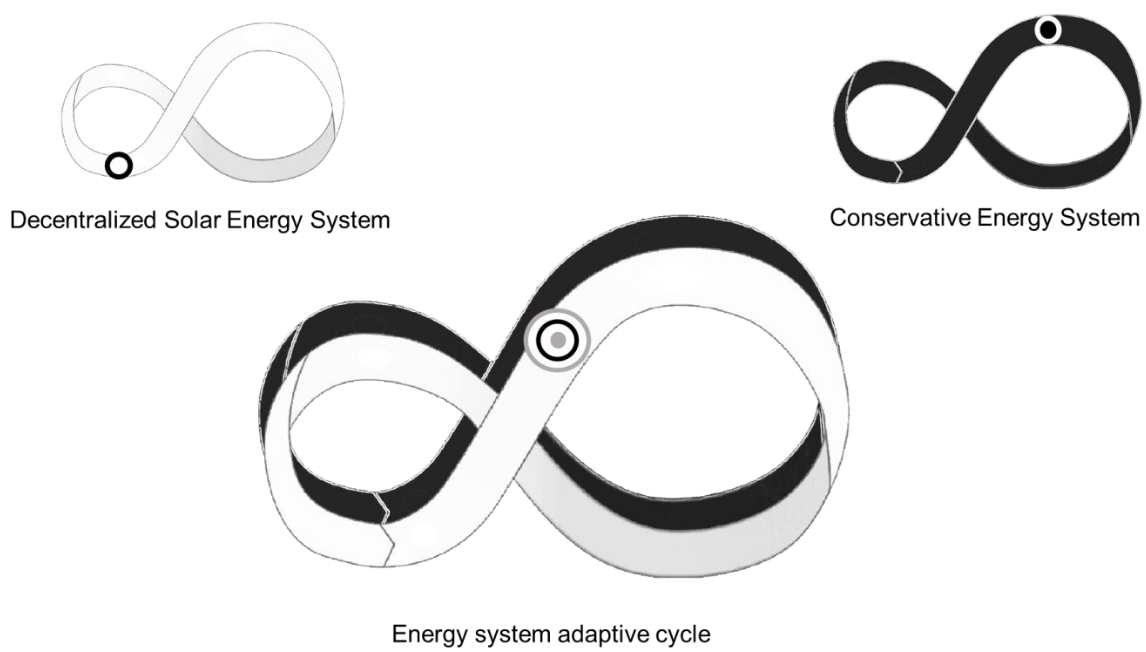

Figure 27- Visual representation of the energy systems convergence. Source: Own elaboration.

The energy system is larger and slower than it was portrayed in previous studies (Dangerman & Schellnhuber, 2013), which is actively changing and adapting still in a conservation phase thanks to the renewable development.

5.1 Transfer opportunity

The outputs obtained regarding the localization of the energy systems within the adaptive cycle, plus the data collected in tables 6 and 7, provides with enough insights to assess the possibility of making a transfer among the two countries, trying to select which polices implemented in Germany to promote the use of decentralized solar energy.

First of all the difference on the phases in which each conservative energy system actually is shows a great difference of circumstances. The German conservative system is on a late conservation phase and even falling or looping into a rigidity trap, but at the same time it is clear that such system is self-aware of the situation and is trying to increase diversity through policies that allow the implementation of solar energy systems. The conservative energy system in Mexico, on the other hand, is still in a stage going from phase r to K, therefore all the sublevels of the panarchy support the current energy scheme, this situation is caused mainly by the amount of reserves the country has. This reserves allows the system to plan and still develop more infrastructure for transportation and increase production, therefore pass through a phase K where, if the system dynamic has not change, will irremediably fall into rigidity trap risking the resilience of the other levels systems and its own. This provides an explanation why even though the country has a great potential, the development of solar energy production has not yet reached a fully exploitation-conservation stage.

The first step that the transfer literature showed is the process of innovation, and within it to identify the need doing so, this rises an inquiry: does the conservative energy system in Mexico requires innovation?, has it reached its peak in the conservation phase?, the answer is no, the system itself does not need innovation to change into a new reorganization, the resilience analysis shows that the system is still profitable and has future and resources to keep growing, all of this taking only into account some systems of the panarchy, the financial-economical and policy mainly, but putting aside the influence of the environment system, the slowest an biggest cycle of the panarchy. The social and community involvement system has not very much influence in the energy system in Mexico since there are not registered or studied cases where a decentralized solar energy system is community owned or community based. On the contrary Germany acknowledges the importance of community based projects through voluntary based policies as one of the main currents to legislate.

The current financial-economical and policy development systems in Mexico, follow the same trend in the phase of the adaptive cycle along with the conservative energy system, so following the multidisciplinary approach that policy transfer requires to have a successful host adaptation, the main opportunities to induce a change in the system, before it reaches a rigidity trap, are the social-community and environmental system. Since the environmental system affects all the levels of the panarchy and all the countries of the world regardless their development, it can be a powerful tool to induce a change in the other cycles. The environment system is not the only system where a policy transfer could be done, the social-community system plays an important role too, the population has a lot of power to make a change with their own hands, choosing better options to supply the own energy demands, such as solar heaters o decentralized PV systems (Figure 28).

Evaluating the previous analysis and due the huge differences between both situations, a transfer form Germany to Mexico may not be that best option to promote end encourage the use of solar systems, nevertheless the analysis clarifies the fields of opportunity to improve the solar energy production in Mexico through.

Community involvement is one of the main strategies towards a resilient based system, trusting in the Adaptive Governance model which consists in a broad and equal power among the organization levels of government, highlighting the need of the community involvement in order to have a sustainable healthy system (ResilienceAlliance, 2010)

The two systems able to withstand the back current of the conservative energy system in Mexico and make a change are the social-community participation and environmental systems.

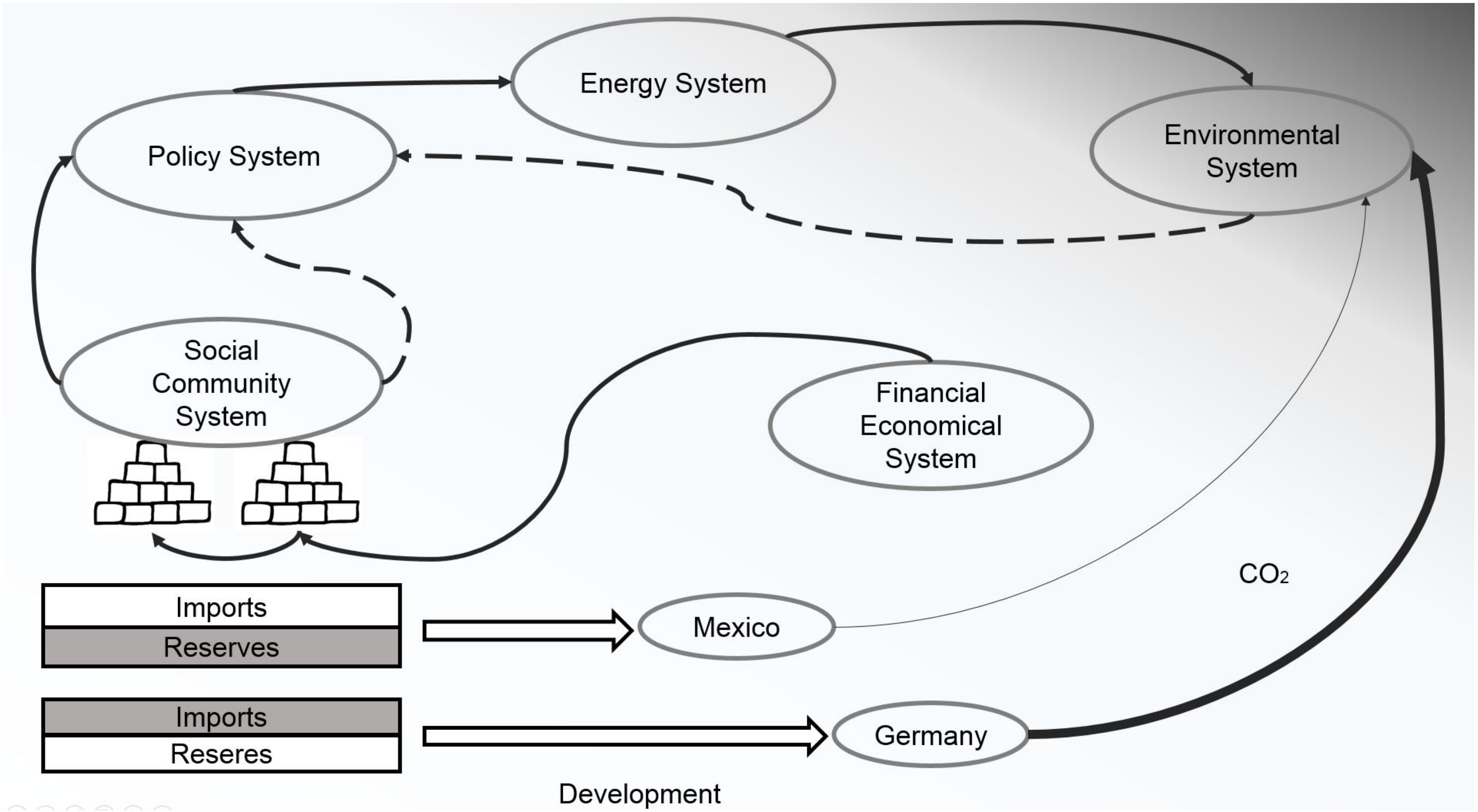

Figure 28 - Interpretation of the energy system panarchy. Source: Own elaboration.

6 Conclusions

After the analysis of results it becomes clear that a system as complex as the energy generation, can coexist with an alternative energy generation system, but the acknowledgement of the necessity to change is the key to evolve into a sustainable production. A huge collapse that leads to a system crisis is not always required, sometimes, as it can be seen in the financial systems, all what is required is an excellent feedback management system, which can actively make a difference. A slow changing system transition can be done.

Policies should be dynamic, changing from time to time, following reserves and environmental damage data, not only changes in the politics or economy of a country.

It seems that in both countries, clearly more pronounced in Mexico, decentralized solar energy generation is just a tool, a tool to maintain the energy system in the conservation phase that reached time ago, the lack or low investment towards solar energy switching or other kind of alternative energy in that matter, shows a probable future getting into a late conservation phase or even getting into a “rigidity trap” with no way out in the horizon, considering the current trends.

It is obvious how the decentralized solar energy system is unable to replace one hundred percent the big sources of energy in a country’s TPES, this is due the physical limitations of the very nature of the source: the sun. The solar geometry has to be taken into account, not all time the sun is showing in the same places, it is rapidly changing. Night is a huge issue to rely totally on solar energy, the storage difficulties presented with the current battery technology price and limitations, stop the potential grow of the technology as well as the other huge important issue, the meteorological situation which is completely uncertain and unpredictable.

It becomes clearer that the adaptive management that may work in some ecosystems can’t work the same way in a socio-ecological complex system as energy generation. For example if a forest starts accumulating potential (biomass) in dangerous levels, that are calculated to produce a collapse in the system, an adaptive management measure would be a moderate induced fire to prevent the system to advance into a late conservation phase (K) where the collapse would lead to a crisis. This cannot be done with the energy system; an adaptive management cannot be directly applied the same way as an ecosystem, since the "accumulated potential" would represent knowledge, jobs, plenty of capital invested in infrastructure, and people themselves. This indicates that the system is in fact very rigid and can be changed through a strong disturbance. But what Gunderson & Holling, (2002) remarked is that not only a huge disturbance can shift the system into a collapse or a new technology exploitation, but also persistent and key disturbances. This way is easier to approach to a solution and start changing towards new technologies such as the decentralized solar systems, through changes that at this time may seem little to overcome the big effects on the environment but find a way of making them persistent and make a change.

An example of these persistent disturbances would be the analysis made in this thesis, where it is obvious how the policy transfer analysis between countries is linked to success thanks to, (among other factors), the space and time approach they have and even if there is no feasible way to make a transfer between the two studied countries, the analysis shows the opportunities to make disturbances or innovate policies specifically for a situation.

Within the energy panarchy, neither the Financial-Economical, the Policy, nor the Environmental systems seem to create disturbances into the energy system to swift its fossil fuel consumption direction, the only system left in the panarchy that can be actively changed and can cause a strong an persistent disturbance is the Social and Community involvement system,

By the means of this research, the decentralized solar system and the conservative energy system were considered as separated adaptive cycles, but the truth is that they coexists, this is only one complex system, that requires a change but not replacing one technology with the other, but find a way to meet halfway and be able to measure the fluxes in the adaptive cycle, and ideally plan changes of phases avoiding great potential loses collapses to maintain the environment healthy.

It is a difficult situation regarding both countries resources reserves, it I clear that Mexico is a country with a considerable amount of fossil fuel resources. In this situation it may appear that Germany has a disadvantage over the world's largest producers reserves, but the truth is that, studying the complex system, having to import a big share of its TPES, gives the country flexibility to change to another exporters in case one of one of the suppliers ran out, in other words German economy is prepared in case of a resource failure since the resources used are not domestic.

Having a huge majority of the TPES domestically produced as it happens in Mexico can be a double edge sword situation, being that, while the reserves endure, the economy and the country are "safe" but at the same time they are not prepared for times of resources scarcity, lacking a backup plan. In terms of resilience and adaptability to change, when an energy system (taking only into account the two cases studied), has a considerable amount of domestic energy resources, it can make its economic and energetic situation rigid and could be hard to recover from a collapse.

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