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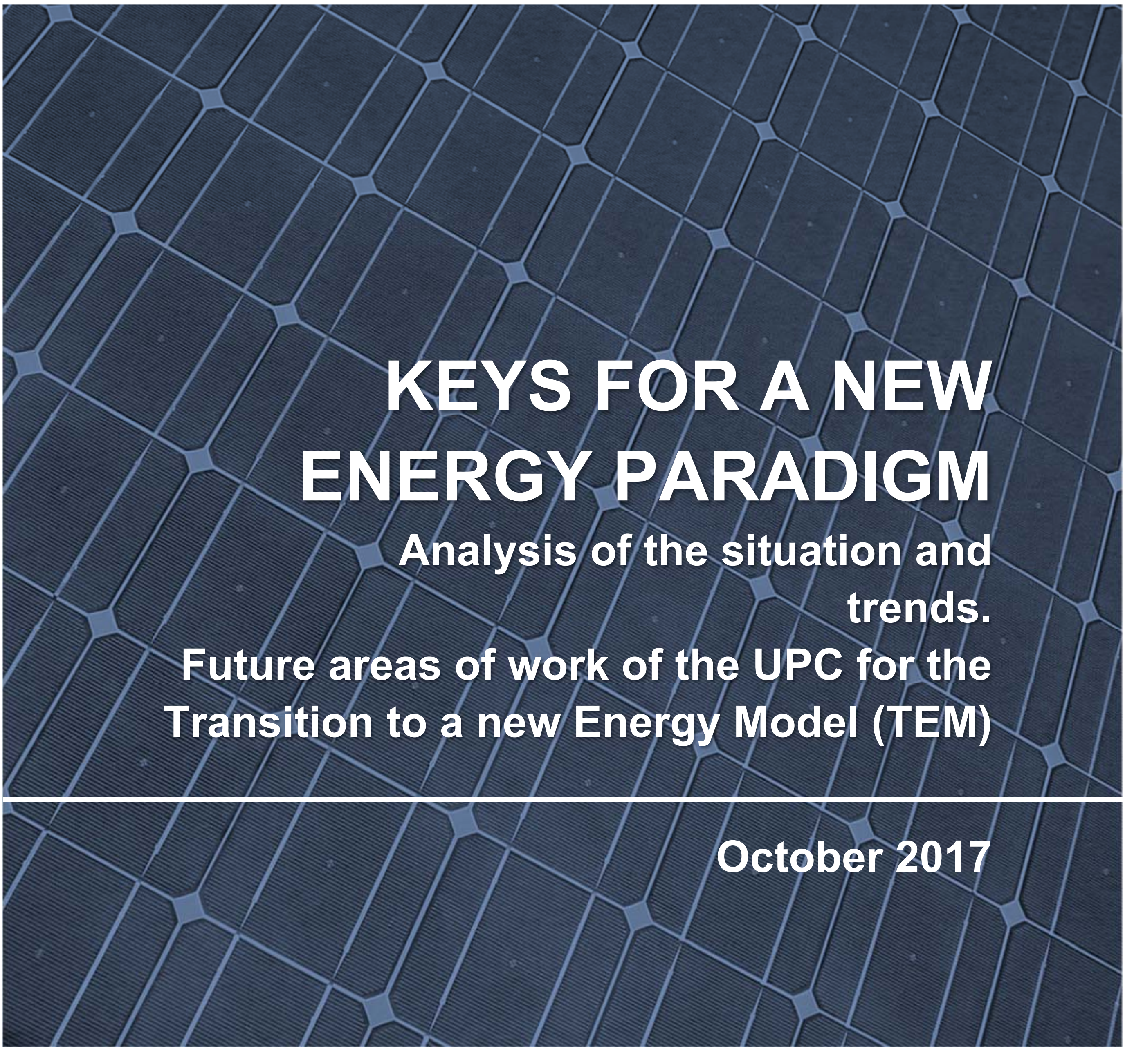


KEYS FOR A NEW ENERGY PARADIGM

Analysis of the situation and trends.

Future areas of work of the UPC for the Transition to a new Energy Model (TEM)

October 2017

The UPC in the face of the energy challenge

It is increasingly clear that we are faced with a systemic crisis. First, there are growing concerns about the decline in non-renewable resources (notably fossil fuels) on a finite Earth. Second, it is ever more difficult for nature to assimilate the impacts of solid, liquid and gas waste generated by a generally linear economy. The most visible indicator of this is climate change. Finally, and no less importantly, the dominant economic system prioritises global markets and reduces public involvement, resulting in less control of inequalities between populations and countries in which scarce natural resources are vital.

These trends threaten the current bases of development and the welfare state, which include food, housing, and access to places, goods and services, information and knowledge, and the materials and energy that support human activities. It is in our hands to change this state of affairs, as stressed in the Agenda 2030 Sustainable Development Goals [NU-ODS-2015] approved by 193 countries. The 17 main goals include affordable and clean energy (Goal 7) and climate action (Goal 13).

Solutions are beginning to emerge, such as promoting a decisive transition to renewable energies, learning to use resources more sustainably, operating in a circular economy in which waste becomes new resources, and strengthening both cooperation and policies to address inequalities. We are immersed in our daily life, in which there is great confusion between the old model and what must become the new one, but it is essential to tackle with determination the profound change required in these new times. Energy, as a resource that is vital to all natural phenomena and all human activities, is a key element that should be the focus of reflections on the inevitable technological and social transition that must take place.

The Universitat Politècnica de Catalunya, as an entity that generates and transmits knowledge, must promote sustainable development and environmental protection in its training, research and institutional activities [UPC-2012]. As the University is aware of this responsibility, it launched a *process of meeting and discussion* to address the energy challenge, with the following objectives:

1. To become a point of reference in energy transition activities.
2. To train, generate knowledge and collaborate to promote the *transition to a new energy model* that is sustainable and socially just, particularly at local and global scale.
3. To raise awareness and encourage debate on this topic among the general public and social and economic organisations, and to foster transformative experiences.
4. To collaborate with political organisations at global and local scale to coordinate the policies and regulations that this transition will require.

As a result of the *process of meeting and discussion*, the UPC has taken advantage of the technical nature of its work to draw up a background document, taking into account the fact that energy resources are essential to all human activities. The document is divided into the following sections:

1. Introduction to the energy transition: a paradigm shift
2. Food and energy
3. Habitability and energy
4. Accessibility, mobility and energy
5. Information, communication and energy
6. Technological processes and energy
7. New energy system and governance.

Each part of the background document contains the following sub-sections: *a*) Analysis of the situation and trends, *b*) Responsibilities and opportunities of the UPC, and c) Future areas of work of the UPC.

The Universitat Politècnica de Catalunya is competent and has a great responsibility for the progress of the energy transition. It can develop alternative solutions for a wide range of the technological processes that support our society and for many processes that provide food, habitability, accessibility, tangible goods, transportation, services, information and communication.

The UPC can also establish a pilot scheme for renewable energy generation and consumption. This can be implemented in the University's buildings and facilities that house teaching, research and technology transfer activities, and by fostering a cultural change in which technology is put at the service of people. The cultural change must be based mainly on new ways of teaching and training future professionals in *the transition to a new model* of energy, economy and society that is more responsible and sustainable.

The scope of these experiences and responsibilities of the UPC as a transformative university must also include the dimension of international cooperation. The focus should be acceptable proposals that can benefit both the local environment and developing countries, in a global international environment.

Core ideas by area

Introduction to the energy transition: a paadigm shift

Civilisation based on easy, abundant energy from non-renewable sources (80% of which are fossil fuels) is coming to an end for two reasons. First, these are finite resources, and reserves will be exhausted in just a few decades at the rate of current consumption. Second, the gases that are released when fossil fuels are burned alter the atmosphere, leading to climate change whose severe consequences are difficult to reverse on the human timescale.

The alternative is renewable energy sources (biomass and hydropower, as well as wind, solar thermal, photovoltaic, marine and geothermal power), most of which are derived from solar radiation. Renewable energies are more than sufficient to meet all current and future human needs. However, the transition from the current energy system (fossil and nuclear) to the new renewable energy system is complex. We must adapt a civilisation that relies on stock resources (concentrated, available while they last and highly intensive) to flow resources (distributed, intermittent and/or random and not very intensive) that need to be harvested over large surface areas, and require new storage systems and new forms of management to regulate energy use over time.

The imminent exhaustion of non-renewable resources cannot be resolved by merely switching technologies. Due to its unique nature, this problem will only be resolved satisfactorily if there is a change in social behaviour and in forms of political and economic organisation. We must shift from a model that values finite stocks, in which the intensive use of energy from fossil fuels is key, to a sustainable model that manages non-finite flows.

Based on its competences and capabilities in teaching, research and knowledge transfer and its responsibility as a public entity, the Universitat Politècnica de Catalunya is committed to *the transition to a new energy model*, particularly in its areas of expertise: technologies and sciences.

This commitment is associated with a context in which the values behind related actions are a holistic view, the promotion of cooperation, work with local resources, the spirit of initiative, knowledge sharing and the concept of universities as tools with transformative capabilities.

The cross-cutting actions that are proposed focus on four main areas: advancing research, testing new solutions in the university community, actively participating in the general debate, and training future generations.

Food and Energy

Nourishment is the first basic condition for the existence of people and human societies. The energy an individual requires from food is a relatively small amount: 2,500 kcal/day, 2.9 kWh/day, equivalent to an average power of 120 W. However, the annual energy associated with food for all humanity, which had reached 7,266 million people in 2014, equates to 5.2% of the anthropogenic energy system, that is, the energy system created by humans.Apart from some synthetic components, the energy content of food is derived from the harvesting of solar energy by primary producers through photosynthesis, which is transferred to other beings via the food web.

As in other areas of human activity, the progressive incorporation of non-renewable energies (particularly hydrocarbons) into the food supply chain has increased the rate of production and its returns in recent decades. Notably, in the last half a century, the cropland that feeds each inhabitant of the Earth has dropped from 0.60 hectares per inhabitant to 0.22 today.

This has occurred at the expense of allocating an increasing amount of energy from the anthropogenic energy system (30% of the total) to the various stages in the food supply chain: primary production (agriculture, livestock farming, aquaculture and fishing); the processing industry; and the distribution, preservation and preparation of foods (in homes and restaurants). In the intensive production model, the primary/food sector, which is focused on providing metabolic energy for human activities, consumes an increasing amount of fossil energy to achieve its objectives.

From the perspective of *the transition to a new energy model*, we must develop alternatives to the massive use of fossil fuels in the food supply chain, particularly in processes of primary production of plants and animals. One particularly critical issue is the treatment of waste, which should be considered a new resource in the framework of a circular economy. We should use our existing biotechnological capabilities to create new organisms that are as efficient as possible with low inputs and that adapt to more diverse production systems, which consequently experience fewer seasonal fluctuations.

Beyond fossil fuels, the main challenge is to establish a new balance between population and territory. For example, under current parameters and according to estimations made by Sans [2014] and Furró [2016], Catalonia would need between 1.25 and 2.0% of its territory to provide renewable energy for its population of 7.5 million. If we take the world average of 0.22 hectares of cropland per inhabitant, Catalonia would require just over 50% of its territory to produce the food that it consumes. Today, agriculture occupies approximately 25% of Catalonia’s surface area. The production of foods using new organisms and production systems could considerably reduce the percentage of cropland that is required.

Habitability and energy

Habitability is an asset that meets the human need for shelter and suitable conditions for individual and community activities.

The first place where habitability is observed is in homes, where individuals' and families' most basic needs are meet: sleeping and resting, preserving and preparing food, personal hygiene, keeping personal belongings, everyday relations, reproduction and childrearing.

However, in a socially acceptable life, habitability is also seen on a larger scale, in services (education, healthcare and culture), workplaces (offices, workshops and factories) or leisure facilities (conference rooms, theatres and sports centres). Through urban planning and mobility, these structures reflect the relation of society with the environment.

In 2014 in the world, the proportion of energy consumption associated with the residential sector was 24.9% of the final energy consumption, and that of the service sector was 8.7% (33.6% in total). In OECD countries the proportions were similar: residential consumption was slightly lower (20%), but compensated for by greater consumption in the service sector. The energy used in the construction and maintenance of buildings could increase operational energy demand by between 10 and 20%.

From the perspective of the *transition to a new energy model*, the main problem in the future is the maintenance of existing buildings and their adaptation to the new renewable energies. The end objective will be to attain nearly zero-energy buildings.

Accessibility, mobility and energy

When food and habitability are secured, the accessibility of places, goods, services, information and knowledge becomes a basic requirement for people's participation and social inclusion. Accessibility (which is a value) should not be confused with the associated activities and the means to make them happen.

Until a century and a half ago, the only form of accessibility was physical (movement of people or goods). However, with the development of the telegraph, the radio, the television and, in recent decades, the internet combined with mobile phones based on powerful computer systems, virtual accessibility is playing an increasingly relevant role. In some fields, virtual accessibility has replaced physical accessibility; in others virtual accessibility competes or collaborates with physical accessibility.

Therefore, accessibility has two basic forms today: physical accessibility in which mobility is the associated activity and transport systems are the means; and virtual accessibility in which the flow of information is the associated activity and communication systems are the means.

Transport is one of the major consumers of energy in current society. It accounts for 30.6% of final energy consumption worldwide and 39.9% in OECD countries. Extreme values are found in Spain (46.0%) and Catalonia (49.9%). In the world, 92.4% of final energy consumption for transport comes from oil. A total of 64.5% of this resource (which is the closest to exhaustion) is used for transport (see [IEA-2017] for the world, OECD and Spain; [Idescat-2017c] for Catalonia).

Therefore, from the perspective of the *transition to a new energy model*, it is vital and pressing to rethink physical accessibility in relation to mobility and transport. First, in terms of energy carriers, a shift is required from oil derivatives to electric systems based on renewable energy (with ways to charge and store energy in vehicles, such as batteries, hydrogen and fuel cells, and the electrification of rail tracks and roads) and to biofuels in certain applications.

However, the entire transport system needs to be transformed. More efficient vehicles are required, and infrastructure must be put to effective use. A new concept and management of mobility must be implemented that prioritises activities in the local area and collective mobility. Above all, synergies with virtual accessibility must be sought.

Information, communication and energy

Information and communication technologies (ICT) have become essential. They enable new information and communication channels (such as mobile phones, social networks and online services), which open up opportunities for virtual accessibility. We are increasingly surrounded by connected systems and devices that gather, process and transmit data and act automatically (data centres, data mining, big data, home automation and remote control).

Given the great complexity and interdependence of ICT and other activities, there are no widely accepted estimations of the energy uses of these technologies. Unlike other sectors, the manufacture of ICT components (which have very low entropy) requires a lot more energy than their use during their useful life. Global energy consumption by ICT can be estimated at between 10 and 15% of final energy consumption (IEA energy balances [IEA-2017]), of which around 80% is consumed during their manufacture ([Williams-2004], [Mobbs-2010]).

Another characteristic feature of ICT is that, at the same time as they consume energy, they contribute to saving it in other activities (in the primary, industrial, services, transport and residential sectors), through dematerialisation (digitalisation) of information and better knowledge and control of processes. It is vital to examine these pathways in greater depth and establish criteria and methods to assess the overall impact of ICT, whose uptake continues to grow. Another relevant challenge is to apply the principles of a circular economy to ICT, for example, to encourage reuse and the recovery of materials (particularly the scarcest) and energy.

Technological processes and energy

Human activities are organised into technological processes, or ordered, interlinked sequences of procedures that use materials and energy, combined with knowledge, to produce goods and services that are useful to people and communities.

The progressive replacement of non-renewable energy sources (stock resources that are concentrated and intensive) for renewable energy sources (flow resources that are distributed, intermittent and/or random and less intensive), as well as the *transition to a new energy model*, has a profound impact on many conventional technological processes.

Future technological processes should be made more efficient and energy losses avoided. Electricity, which must be obtained increasingly from renewable sources, will be much more abundant than fuels. Hence, many processes will have to be adapted to this new vector (e.g. electric traction and heat pumps). The places and times at which processes are operated should be adapted as far as possible to the places and times of the energy sources (solar radiation, water currents and winds). Equally, as far as possible, we should avoid systems that operate at times when there is little energy generation and stored energy is required, and those that need substantial amounts of energy to be loaded onto vehicles or independent systems. In all these systems, energy uses would be less efficient and more expensive.

Therefore, prior to the introduction of new renewable energies, the technological processes associated with different activities should be reviewed critically to: improve their energy efficiency, study cases in which a change of energy carrier is advisable, reduce as far as possible the number of steps in energy pathways from sources to uses.

Energy sistem and governance

The crisis of non-renewable energies and the vital *transition to a new energy model* based on renewable sources will lead to a profound transformation of the entire system that supplies energy to all human activities, and to the governance of this system.

The current global energy system, in which 95.9% of cases involve combustion, is extremely inefficient: a total of 32.5% is lost from primary energy to final energy consumption; and 59.6% is lost from primary energy to useful energy, which is what really drives processes and moves devices. Hence, only 40.4% is used (in countries with excessive transportation, the situation is even worse: 62.6% of energy losses in Spain and 66.4% in Catalonia) ([IEA-2017], Idescat-2017c]). This can be explained largely by the fact that the efficiency of electricity generation is 33% on average, and the efficiency of vehicle propulsion (land, sea and air) is 25% on average. Only thermal systems based on combustion have higher efficiency values (they can reach up to 90%) [Furró-2016].

Much of the new renewable energy system will be based on technologies that generate electricity directly and is counted as such (hydroelectric, wind, photovoltaic, marine and biological power, as biotechnological systems can also generate energy). Therefore, the entire system will be much more efficient as today most electricity is obtained from combustion, which has an average efficiency of 33%. Additionally, efficiency is improved by gases such as biomethane that are obtained from renewable sources and consumed directly for thermal uses in the surrounding area.

Therefore, instead of the current energy system that uses 2.5 units of primary energy for each unit of useful energy, the new renewable system will use only between 1.4 and 1.8, depending on the forms of governance that are adopted, particularly regarding storage.

The major technological challenges that must be met by the new renewable system are massive energy storage (mainly for electrical energy) to resolve the lack of synchrony between energy harvesting and use (day/night, summer/winter) and loading sufficient amounts of energy on vehicles that has limited weight and space.

Other challenges are to determine where to situate extensive energy harvesting systems. In Catalonia, for example, between 40,000 and 60,000 hectares will be needed, that is, from 1.25 to 2.0% of the surface area. The current, one-way electricity grid (from large generators to consumers) will have to be made multi-directional (many generators and many consumers), and must include storage systems and vehicle charging stations, among other elements [Furró-2016].

Hydrogen obtained from hydrolysis of water and its subsequent use in fuel cells (hydrogen-electricity) or as a fuel is likely to play a relevant role in the new renewable system. It could have three basic functions: massive electrical energy storage at times of low consumption; a way to carry energy on heavy and long-distance vehicles; and in combustion chambers for high-temperature industrial processes.

The emergence of new ways of obtaining energy (such as generation for own use or self-consumption or generation in collective facilities) will empower people and force a change in the grids from hierarchical to distributed. At the same time, the tariff system must be adapted to this new model and encourage saving.

Contributions of the UPC

The process of *meeting and discussion* within the Universitat Politècnica de Catalunya (UPC) from 2014 to 2017, in the various gatherings and symposiums that were held, led to the identification of a series of *core areas* centred on the main conclusions of the background document.

From a methodological perspective, the conclusions are focused on promoting:

METHODOLOGICAL PRINCIPLES

- **A HOLISTIC VIEW**

Transform work based on niches of interest into more general work that has a holistic, integrative perspective.

- **KNOWLEDGE SHARING**

Work in dynamics of multidisciplinary teams to build synergies between specialisations.

- **PROMOTION OF COOPERATION**

Promote respect and knowledge of our natural and social environment. Encourage service-learning for our students to resolve real problems, with solutions that can be transferred to society.

- **WORK WITH LOCAL RESOURCES**

Value resources that are in the local environment, considering the characteristics of distribution and the proximity of renewable energy sources.

- **INVOLVEMENT OF ALL**

Encourage participation of the entire university community so that sustainability becomes an inherent, cross-cutting aspect of engineering.

- **SPIRIT OF INITIATIVE**

Foster active, imaginative, goal-based learning. Boost initiative, entrepreneurialism and the creativity of students, teaching and research staff, and administrative and service staff.

- **A TRANSFORMATIVE UNIVERSITY**

Have an impact on all the University's areas of responsibility, with a focus on acceptable proposals that benefit both the local environment and developing countries, in a global international environment.

The conclusions of this document also establish a series of cross-cutting actions and actions centred on the University's subject areas:

CROSS-CUTTING ACTIONS

- ### ADVANCE RESEARCH

Boost current research areas that are in line with the TEM project: acknowledge, disseminate and strengthen them. Promote new strategic areas of research that emerge as alternatives for the future, foster them and provide resources for them.

- ### TEST NEW SOLUTIONS

Collaborate with the environment: with the production system, governments and administrations, associations and civil society. Promote pilot schemes in the University environment.

- ### TRAIN FUTURE GENERATIONS

Contribute decisively to training future professionals and leaders in the transition to a new energy model, with a general education project that is based on present and future sustainability.

- ### PARTICIPATE ACTIVELY IN THE GENERAL DEBATE

Be actively involved in drawing up proposals for the general debate on the new energy model and the associated social transformations.

ACTIONS BY SUBJECT AREA

- ### FOOD AND ENERGY

Promote the incorporation of key enabling technologies (KETs) for industry 4.0 into the agri-food sector; stimulate research on food at the UPC from the perspective of a basic service, using new, integrating concepts focused on the energy transition; provide services for compiling food balance sheets for Catalonia; and work on all aspects relating to wastage of food and water.

- ### HABITABILITY AND ENERGY

Promote a view of habitability as a need to be met by architecture, construction and the city; work to achieve efficiency and suitable uses of energy and other resources in relation to buildings and urbanised areas; above all, work to meet the challenge of nearly zero-energy buildings (nZEB) and to develop new models of services that contain green infrastructure for connecting the territory, and provide the fabric required to transform the existing city.

- **ACCESSIBILITY, MOBILITY AND ENERGY**

Offer government bodies the capacity to participate in an analysis of accessibility; continuously monitor the evolution of mobility; develop new concepts of battery-powered urban electric vehicles and develop support technologies; promote the research and development of hydrogen as an energy carrier for heavy and long-distance transport; and promote studies on when physical or virtual accessibility or a combination of both is most appropriate. In all cases, develop new forms of accessibility.

- **INFORMATION, COMMUNICATION AND ENERGY**

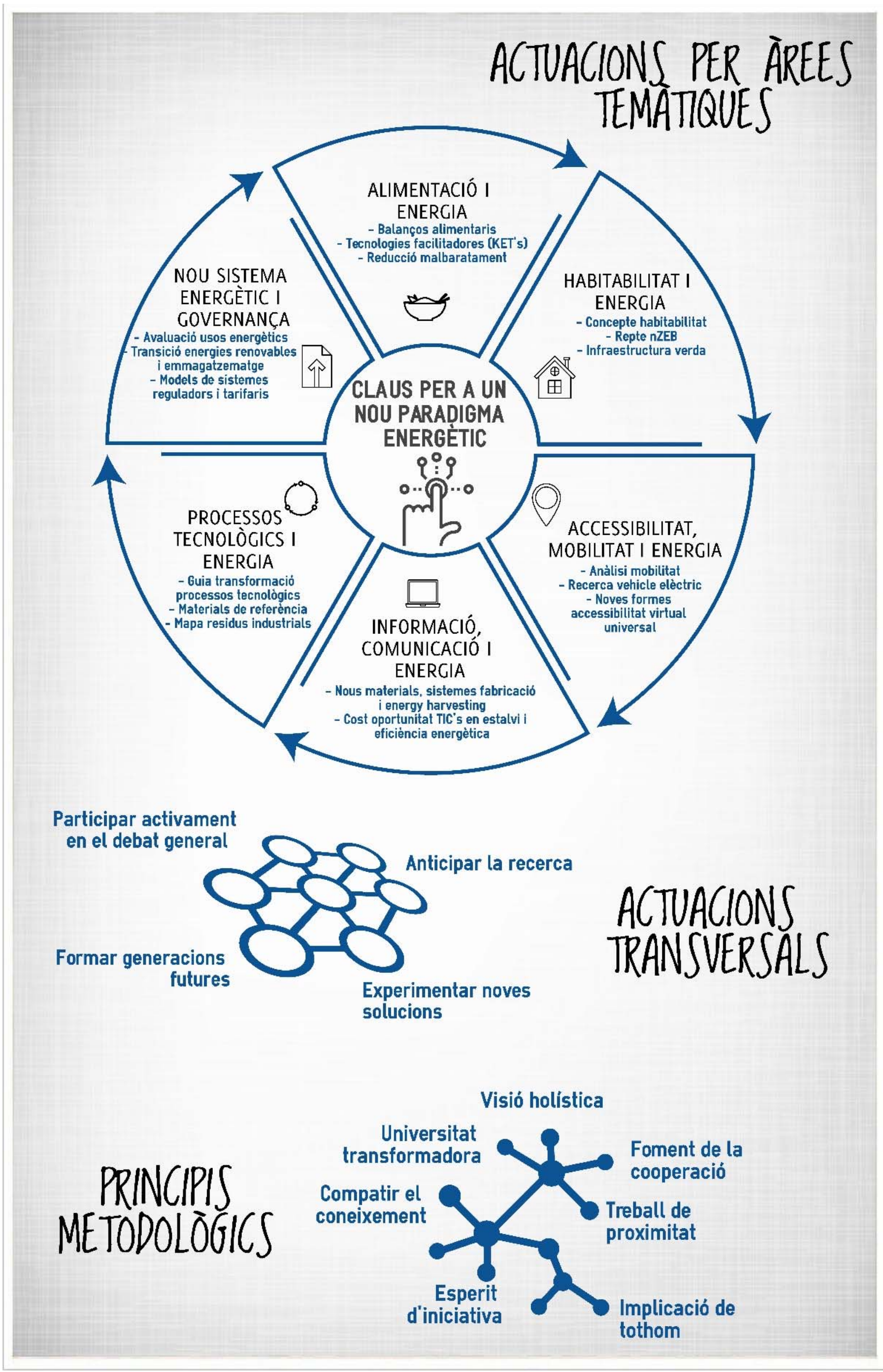
Propose new methods and new materials to optimise the energy required to manufacture integrated circuits; research new materials to manufacture electronic circuits that reduce the need for rare earth elements, highly contaminating materials and/or materials that come from conflict areas; develop and improve energy harvesting techniques; analyse the opportunity cost associated with the use of ICTs in processes of energy saving and efficiency; and work to avoid the impact of technical and human ICT errors and external attacks on the overall and energy efficiency of the economic system.

- **TECHNOLOGICAL AND ENERGY PROCESSES**

Methodically review technological processes from energy and environmental perspectives; focus on how materials are obtained (cement, ceramics, glass, steel, metals and polymers), as this tends to have more impact on energy and the environment than the subsequent processes of construction or transformation; establish reference lists of materials and promote more responsible use of them (minimise, optimise or replace), whilst developing alternatives; analyse waste and the end-of-life to foster the circular economy; and develop guidelines for the transformation of technological processes.

- **NEW ENERGY SYSTEM AND GOVERNANCE**

Participate in the transition of the energy system to renewable sources (thermal solar, hydraulic, photovoltaic, wind, geothermal and biomass power) that has new agents (those who generate power for their own uses), new functions such as storage (in which hydrogen is expected to play a key role) and grids that must become distributed; work on transition in transport to renewable energy carriers; develop and maintain tools to determine and assess energy uses in sectors of activity, in line with the ECESI survey by the Catalan Energy Institute (ICAEN) on industrial uses; and study and propose ways of empowering people and models of regulatory and tariff systems that suit the dynamics of the new, distributed renewable energy system.


ACTUACIONS PER ÀREES TEMÀTIQUES
ALIMENTACIÓ I ENERGIA
- Balanços alimentaris
- Tecnologies facilitadores (KET's)
- Reducció malbaratament
HABITABILITAT I ENERGIA
- Concepte habitabilitat
- Repte nZEB
- Infraestructura verda
ACCESSIBILITAT, MOBILITAT I ENERGIA
- Anàlisi mobilitat
- Recerca vehicle elèctric
- Noves formes accessibilitat virtual universal
INFORMACIÓ, COMUNICACIÓ I ENERGIA
- Nous materials, sistemes fabricació i energy harvesting
- Cost oportunitat TIC's en estalvi i eficiència energètica
PROCESSOS TECNOLÒGICS I ENERGIA
- Guia transformació processos tecnològics
- Materials de referència
- Mapa residus industrials
NOU SISTEMA ENERGÈTIC I GOVERNANÇA
- Avaluació usos energètics
- Transició energies renovables i emmagatzematge
- Models de sistemes reguladors i tarifaris
CLAUS PER A UN NOU PARADIGMA ENERGÈTIC
Participar activament en el debat general
Anticipar la recerca
Formar generacions futures
Experimentar noves solucions
ACTUACIONS TRANSVERSALS
Visió holística
Universitat transformadora
Foment de la cooperació
Compatir el coneixement
Treball de proximitat
Esperit d'iniciativa
Implicació de tothom
PRINCIPIS METODOLÒGICS

1. Introduction to the energy transition: a paradigm shift

Contents

1.1 Analysis of the situation and trends

1.1.1 Evolution of the energy in the world

Until a few decades ago, the Earth provided sufficient resources to sustain expanding human activity, in terms of the intensity of resource use, the capacity to assimilate waste, and the number of people who enjoyed the resources, that is, the population.

At certain points in history, resources have become exhausted locally, leading to the abandonment of certain activities or territories, or resources have become partially exhausted. Now, the first global limits can be perceived. The most notable indicators of this new situation are the scarcity of fossil fuels (particularly conventional oil) and anthropogenic climate change, which is today widely accepted.

In addition to the energy and climate problem, wealth and economic power are becoming concentrated globally, and production processes and forms of organisation are increasingly opaque. There is also a tendency to cut the workforce. These factors make it even harder to resolve the severe problems that have arisen and to make decisions.

Evolution of the human energy system

Figure 1.1 shows the evolution of the human energy system in the last two-and-a-half centuries. The following periods are particularly notable:

1750 to 1850
In this first hundred years of the period under analysis, energy use worldwide rose from 3,500 to 6,150 TWh (mainly of biomass). This figure includes coal use, which increased from 30 to 610 TWh per year.

1850 to 1945
With the development of the railway from 1925, the use of coal increased. It surpassed the use of biomass in around 1905, and stood at approximately 8,800 TWh in 1910. This value then fluctuated and reached 9,300 TWh in 1945. The use of biomass increased moderately up to 7,200 TWh in 1945. The automobile industry drove the consumption of crude oil, which rose from 300 TWh in 1900 to 4,300 TWh in 1945. The production of natural gas and hydroelectricity followed a similar pattern, with a slight delay, and reached 1,200 and 400 TWh in 1945, respectively.

1945 to 1973

The dramatic rise in the use of crude oil occurred after the Second World War. In 28 years, oil production increased by over a factor of seven to reach 31,400 TWh (45.1% of the energy mix) at the time of the 1973 oil crisis. Natural gas use increased even more sharply (by a factor of 9), but reached lower absolute values (11,100 TWh in 1973), while coal use only doubled (17,900 TWh). Therefore, in 1973, fossil fuel production accounted for the highest proportion of the global energy mix of 69,600 TWh, at 87.4%.

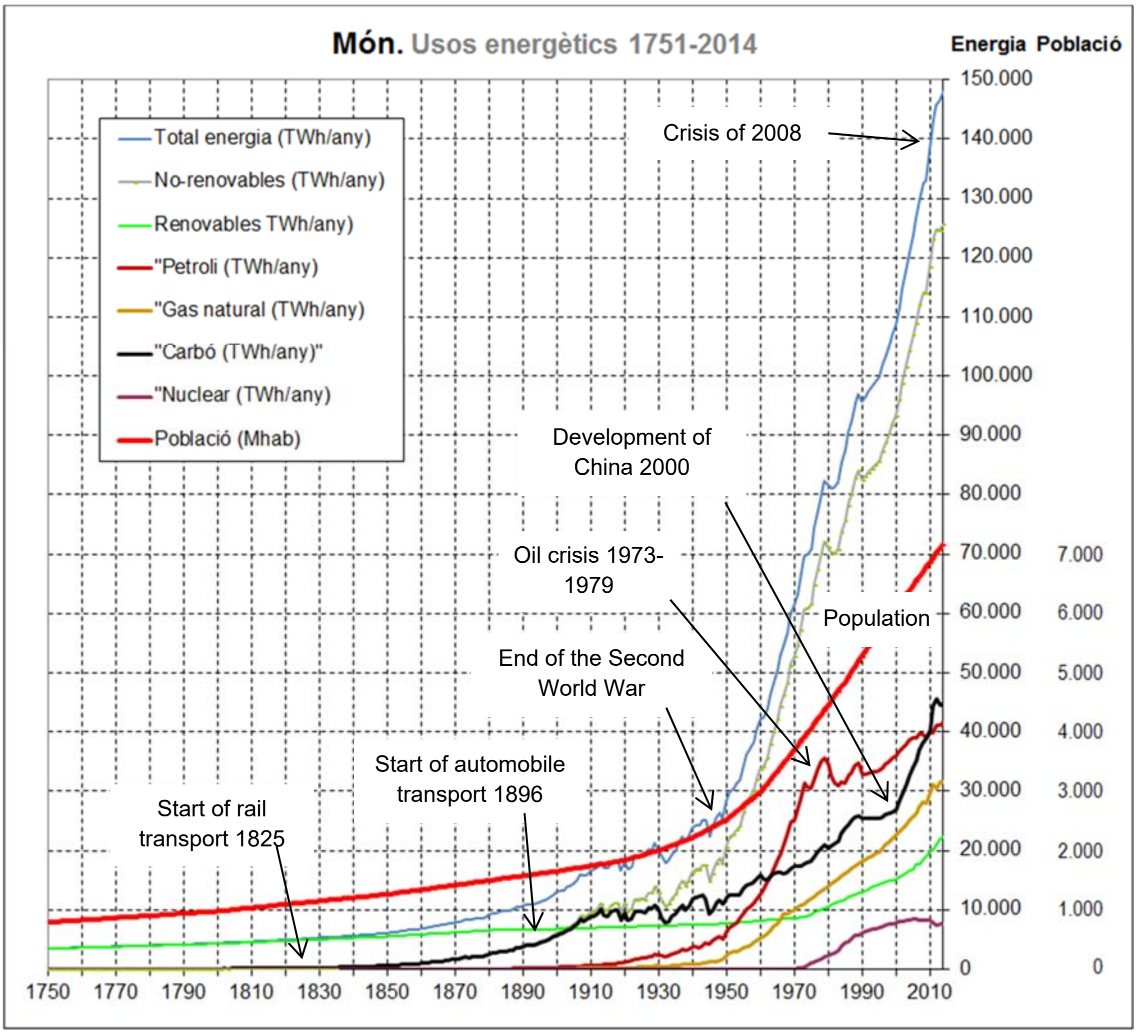


Figure 1.1 Sources: historical data, based on CO_2 emissions estimated by CDIAC [CDIAC-2014]; data for recent years, International Energy Agency [IEA-2016];.

Oil crises of 1973 and 1979

The oil crises were the result of a conflict: oil producing Arab countries limited the supply of countries that had supported Israel. Prices rose and oil consumption stagnated for a decade (it stood at 30,900 TWh in 1983). The use of other fossil fuels went up slightly, nuclear energy began to be introduced and renewable sources grew. Altogether, energy production worldwide reached 82,100 TWh in 1983.

Further expansion until the 2008 crisis

From 1983, the price of oil and fossil fuels began to drop again, and the use of energy rose during a lengthy period of 25 years, to reach 132,600 TWh in 2008. In this period, the main fuels responsible for the increase in energy consumption were coal, driven by its use in China and other Asian economies (38,000 TWh, a 77.0% increase), and natural gas (28,200 TWh, an 85% increase). The use of oil went up 28% to 39,500 TWh. Nuclear energy expanded rapidly from 1969, and reached a maximum in 2006 (8,500 TWh), but the Fukushima accident in 2011 marked the start of its decline.

In this period, renewable energies made great advances: hydroelectricity increased 79% to reach 3,200 TWh in 2008; other renewable energies rose by almost a factor of four to reach 1,040 TWh; and biomass increased by over 50% to reach 14,200 TWh in 2008, particularly in the less developed countries of Sub-Saharan Africa, South East Asia and Latin America, where biomass is not always obtained sustainably. However, the growth in renewable energies parallels that of non-renewable energies, so that the percentage of renewable energies only increased to 13.9% in 2008.

Crisis of 2008 and subsequent trends

After a prolonged period of economic growth associated with the consumption of resources and energy, in 2008 a global crisis emerged that was initially associated with mortgages, then became financial and ended up affecting the entire economy.

Although we only have a limited view of the situation, the effects of the exhaustion of energy resources are beginning to be seen, particularly in relation to fossil fuels and oil. The price of crude oil reached its highest value ever on 11 June 2008 (147.27 $/barrel), fell the following year (2009) to under 40 $/barrel, rose to values of around 80 $/barrel in 2010, remained above 100 $/barrel from 2011 to 2014, fell again at the end of 2015 to values of between 30 and 60 $/barrel (forced by Saudi Arabia in particular), and now seems to be rising again.

Table 1.1 shows trends in energy production and consumption in 2008-2014:

Table 1.1 Variations in energy uses, 2008-2014

	Total	Fossil fuels	Oil	Natural gas	Coal	Non-ren.	Ren.
WORLD	11,7 %	11,4 %	5,1 %	11,9 %	17,7 %	10,1 %	21,5 %
OECD	-4,1 %	-5,9 %	-9,3 %	4,3 %	-11,5 %	-6,8 %	28,3 %
NoN-OECD	25,2 %	26,7 %	22,7 %	20,0 %	33,3 %	26,6 %	19,2 %
EU-28	-11,4 %	-17,8 %	-16,7 %	-23,4 %	-12,1 %	-16,1 %	34,6 %
Spain	-14,9 %	-24,4 %	-21,6 %	-32,9 %	-16,9 %	-21,9 %	93,6 %
Catalonia	-8,2 %	-15,6 %	-9,6 %	-23,3 %	-91,2 %	-10,4 %	9,4 %

Sources: [IEA-2016], [Idecat-2016a]

Global energy use increased by 11.7% (and the use of fossil fuels by 11.4%, with larger rises in coal and natural gas use than in oil consumption), but very unevenly. Consumption dropped in OECD countries (-4.1%), but went up by 25.2% in non-OECD countries (particularly China and emerging countries). There was a notable increase in the use of coal, which has the greatest environmental impact, in non-OECD countries (33.3%). The reduction in energy consumption in Europe was greater than that observed in OECD countries: Catalonia (-8.2%), EU28 (-11.4%) and Spain (-14.9%).

Despite the difference in the increase of non-renewable (10.1%) and renewable (21.5%) energies, the impact on the global balance is small, as non-renewable sources account for a high percentage of the global energy mix. In OECD countries, the use of non-renewable energies dropped (-6.8%), while that of renewable energies rose noticeably (28.3%). In the EU28 and Spain these trends were more marked. In contrast, in Catalonia the increase in renewable energy use was very small. In non-OECD countries, many of which are in the process of developing, the increase in renewable energy use is much lower than that of non-renewable energies.

Evolution in oil prices

The prices of crude oil (Figure 1.2), which are higher than those of other fossil fuels (approximately double that of gas and four times that of coal, for the same amount of energy), have been very low over prolonged periods in the past. There have only been three episodes of high prices: in the initial boom in around the 1860s and 1870s; during the political oil crises of 1973 to 1983; and in the current resource and environmental crisis, particularly after 2008.

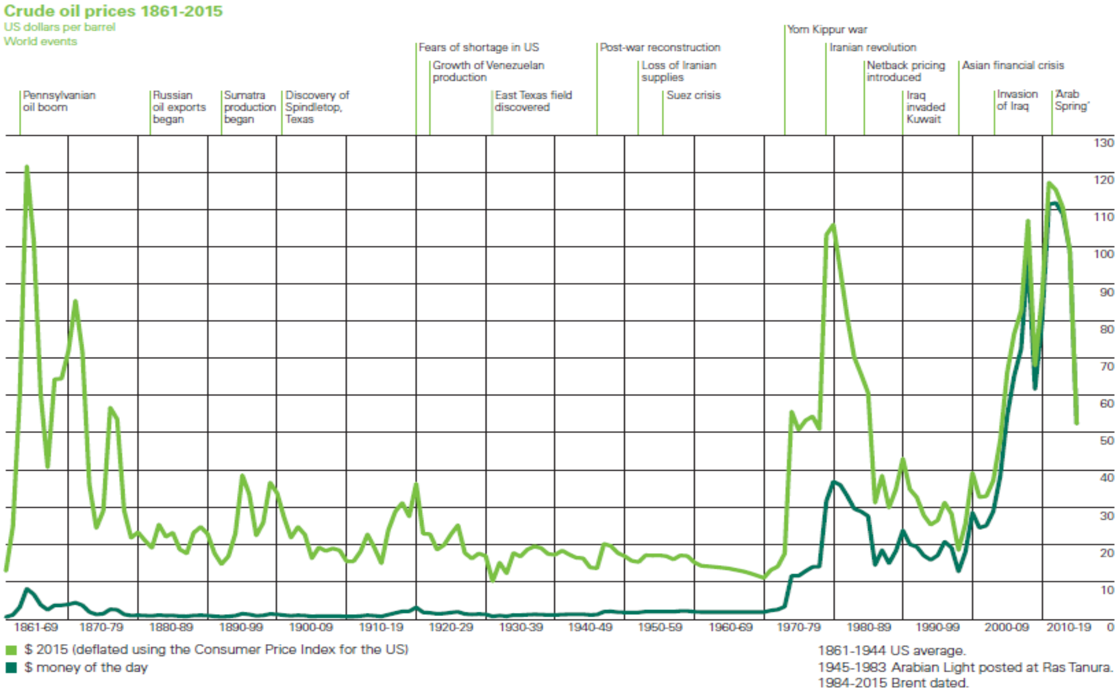


Figure 1.2 Crude oil prices over time, at current values and 2015 values.
Source: BP Statistical Review of World Energy, June 2016 [BP-2016]

These strong fluctuations in prices accompanying an economy that is also unstable could be symptoms of a change in era in which energy and resources will be the main issue. Although latest indications indicate a certain degree of economic recovery in developed countries, there seems to be a slowdown in the economies of emerging countries.

1.1.2 Energy uses and sectors of activity

We need to know how energy is used in sectors of activity in order to develop alternatives.

Table 1.2 is based on energy balance data for 2014 compiled by the IEA [IEA-2017] for the world, OECD countries, non-OECD countries, the EU28 and Spain, and IDESCAT data [Idescat-2017a] for Catalonia. The figures given below do not include non-energy uses of fossil fuels (in polymers, fertilisers and other products).

In the IEA energy balances, primary energy from renewable electricity sources (hydroelectric, photovoltaic, wind and marine power) is counted as electricity and undervalued compared to fuels in the overall calculation. Indeed, in 2014, nuclear primary energy (thermal) accounted for 5.2% of the global energy mix, while hydroelectricity stood at 2.6%. However, electricity generated by nuclear sources stood at 2,540 TWh (9.2% of the global total), while that generated by hydroelectricity was

3,980 TWh (14.3%). The same pattern can be found with wind, photovoltaic and marine power.

The primary energy used in 2014 in the world (Table 1.2) was 148,140 TWh (20,390 kWh per inhabitant per year). A total of 84.8% of this amount corresponds to non-renewable sources: fossil fuels that emit 32.38 billion tonnes of CO_2 equivalent (4.46 tonnes per inhabitant per year) and uranium. The remaining 15.1% corresponds to renewable sources (hydroelectricity, biomass and other renewable energies). Once transformed into final energy (commercial fuels and electricity), the primary energy was reduced to 99,980 TWh (13,760 kWh per inhabitant per year) and lost 32.5% of its initial power.

OECD countries, with 17.5% of the world population, produce 29.5% of the primary energy, use 39.6% (46,190 kWh per inhabitant per year) and generate 36.6% of the greenhouse gases (9.34 tonnes of CO_2 equivalent per inhabitant per year).

In contrast, non-OECD countries, which account for 82.5% of the world population, produce 70.5% of the primary energy, use 60.4% (14,910 kWh per inhabitant per year, three times less than OECD countries) and emit 63.4% of the greenhouse gases (3.42 tonnes of CO_2 equivalent per inhabitant and year; three times less than OECD countries).

In Europe, these figures are high, but lower than those for all OECD countries (35,500 kWh per inhabitant per year and 5.96 tonnes of CO_2 equivalent per inhabitant per year), slightly higher than figures for Spain (30,160 and 4.97) and Catalonia (35,230 and 4.83).

Table 1.2 Energy uses in 2014 by geographic area and sector of activity							
		World	OECD	Non-OECD	EU28	Spain	Catalonia
Population	10^6 habitants	7.265	1.270	5.995	505	46,8	7,5
	% world	100,0 %	17,5 %	82,5 %	6,9 %	0,64 %	0,10 %
PE: production	**TWh/a**	**149380**	**43.710**	**105680**	**7.750**	**355**	**60**
	% PE[1] supply	100,8 %	74,4 %	118,2 %	43,2 %	25,1 %	22,8 %
	% world	100,0 %	29,5 %	70,5 %	5,2 %	0,24 %	0,04 %
PE: supply	**TWh/year**	**148.140**	**58.720**	**89.410**	**17.930**	**1.410**	**265**
Per capita	kWh/(inhab·yr)	20.390	46.190	14.910	35.500	30.160	35.230
	% world	100,0 %	39,6 %	60,4 %	12,1 %	0,95 %	0,18 %
Non renewable	% EP supply	84,8 %	89,7 %	81,6 %	86,0 %	85,5 %	93,1 %
Renewable	% EP supply	15,2 %	10,3 %	18,4 %	14,0 %	14,5 %	6,9 %
Greenhouse gas emissions	**$TgCO_{2eq}$/a**	**32.380**	**11.970**	**20.520**	**3.010**	**233**	**36**
Per capita	$MgCO_2$/(inhab·yr)	4,46	9.34	3,42	5,96	4,97	4,83
	% world	100,0 %	36,6 %	63,4 %	9,3 %	0,73 %	0,11 %
TFC: total final consumption	**TWh/a**	**99.980**	**40.090**	**59.890**	**12.570**	**1.000**	**175**
Per capita	kWh/(hab·a)	13.760	31.530	9.990	24.910	21.360	23.140
	% EP supply	67,5 %	68,3 %	67,0 %	70,1 %	70,9 %	66,0 %
	% world	100,0 %	40,1 %	59,9 %	12,6 %	1,00 %	0,17 %
Agricult., fishing	% TFC	2,3 %	1,9 %	2,6 %	2,3 %	3,2 %	2,7 %
Industry	% TFC	32,0 %	23,5 %	37,7 %	23,6 %	22,4 %	23,7 %
Services	% TFC	8,7 %	13,9 %	5,1 %	13,0 %	10,3 %	10,6 %
Transport	% TFC	30,6 %	39,9 %	24,3 %	36,3 %	46,0 %	49,9 %
Residential	% TFC	24,9 %	20,0 %	28,2 %	24,3 %	17,1 %	13,1 %
Not specified	% TFC	1,5 %	0,8 %	2,1 %	0,4 %	1,1 %	0,0 %

[1] If production is greater than supply, energy is exported. PE = Primary Energy; TFC = Total Final Consumption. International aviation and shipping energy has been included, and non-energy uses have been excluded. ***Sources:*** *World, OECD, Non-OECD, European Union (EU28); Spain, International Energy Agency [IEA-2016]; Catalonia, Statistical Institute of Catalonia [Idescat-2017a].*

In the distribution of total final consumption between sectors of activity, industry was the heaviest user in the world (32.0%), followed closely by transport (30.6%) and, at a certain distance, by the residential sector (24.9%). At a much greater distance were services (8.7%) and with almost negligible values, the primary sectors (agriculture, forestry and fishing, 2.3%).

This distribution varies widely between the geographic areas. In OECD countries, transport accounts for the highest percentage of energy use (39.9%), followed at a certain distance by industry (23.5%) and the residential sector (20.0%), and energy use by the service sector is significant (13.9%). In contrast, in non-OECD countries, energy use by the industrial sector is notable (37.7%; these are the factories of the world), followed by the residential sector (24.3%) and transport (24.3%, the lowest figure), while energy use by the service sector is much lower (5.1%).

The distribution of energy use in Europe is similar to that of the OECD, with a predominance of use in transportation. Spain and Catalonia are the most unbalanced of this group: Spain uses 46.0% of energy for transport and 17.1% for the residential sector, and Catalonia uses 49.9% for transport (an inappropriate amount) and 13.1% in the residential sector.

1.1.3 The limits of the fossil model

Fossil fuels are the energy resources that enabled the development achieved in the last two centuries. Today their use is suffering a crisis for two reasons: *a*) the easiest, cheapest resources to obtain are being used up, and fossil fuel supply increasingly relies on lower quality resources that are less accessible and more expensive (the prime example are oil sands or tight oil and shale gas obtained by fracking); *b*) beyond local (smog in cities) and regional (acid rain in forests) pollution, the CO_2 that is generated by fossil fuel combustion has a persistent, cumulative effect on climate change.

Exhaustion of reserves

Various studies (including [Riba-2011] using data from 2008) indicate that if current trends in consumption continue, non-renewable energy resources will be exhausted in a few decades. Most of the official reserves that have been added recently correspond to resources that are difficult to extract, have decreasing energy yields and increasing environmental impacts, and will only push back the total exhaustion of resources by a few years. Furthermore, doubts have been expressed about some of the Middle East countries' self-stated reserves, which represent a substantial proportion of global reserves.

Worse still, the problem of non-renewable energy resources will be apparent long before they are exhausted. Peak production will have a dramatic impact on economic growth, whose pattern has always been one of expansion. The first symptoms were seen in the recession of 2008.

The future exhaustion of fossil fuels will affect other mineral resources such as phosphorus, which has very geographically localised reserves in the world. Phosphorus is a key element for the food system, so its recovery from waste and wastewater must be promoted.

Climate change

The Earth's atmosphere contains various gases (particularly water vapour, which is self-regulated, and carbon dioxide that remains and accumulates) that have a greenhouse effect. These gases are transparent and allow solar radiation to pass through them, but they absorb and retain part of the infrared radiation that the Earth returns to space. Thus, they contribute to the fact that the average temperature of the Earth's surface is 15°C (suitable for life). Without the greenhouse effect, it would be around -20°C.

The current problem is that human activities, particularly relating to the combustion of fossil fuels, increase the amount of greenhouse gases in the atmosphere (mainly CO_2), which leads to a rise in temperature. Climate change threatens the composition, capacity for recovery and productivity of natural ecosystems and, in turn, affects the social and economic development, health and well-being of humanity.

The Intergovernmental Panel on Climate Change (IPCC) is a UN organisation that was founded in 1988 with the participation of governments worldwide. Its aim is to gather scientific information on climate change to support governments' decisions. Since its foundation, it has published five Assessment Reports (AR), the last of which was released in 2014.

The international scientific community agrees on some points: a) it is estimated that a limit of 2°C of global warming is the maximum that can occur without significant changes to climate patterns and the maximum that ecological systems can support without undergoing major transformations; b) to limit global warming to 2°C by 2100, the concentration of CO_2 equivalent must not exceed 450 ppm (parts per million). It has already reached 400 ppm, in comparison to 270 ppm in the preindustrial era, and is rising by 1.5 to 2 ppm/year.

To attain this objective, AR-5 examined various scenarios, the most reasonable of which would be to cut greenhouse gas (GHG) emissions by between 40 and 70% by 2050, and by 100% by 2100. Negative emissions may even be needed, i.e., more CO_2 may need to be captured than emitted. Depending on how long it takes to adopt measures to reduce emissions, the required cutback may be or less pronounced or it may even be impossible to keep the concentration of CO_2 equivalent under 450 ppm.

1.1.4 The need for a new energy model

The alternative: renewable energies

Fortunately, the Sun radiates a constant flow of 175,000 TW to the Earth (1,530,000,000 TWh per year), which is around 10,000 times more than the energy in the current human energy system [Riba-2011]. Numerous studies and proposals worldwide support renewable energies as an alternative, and there is increasing agreement on an energy transition to 100% renewable energies before 2050, see among others: [SRU-2010], Germany; [CEESA-2012], Denmark; [Think-2011], Europe; [FPB-ICEDD-VITO-2013], Belgium; [Jacobson-2014], California; [Kivi-2014], Netherlands; and [Zhongyng-2016], China.

In Catalonia, studies by R. Sans and E. Pulla [Sans-2014] indicate that for the main European countries and Catalonia, a transition to 100% renewable energy by 2050 is technically viable and economically much more beneficial than not making the transition. A study by E. Furró [Furró-2016] establishes the phases and prioritises the technologies for undertaking the energy transition in Catalonia. In 2017, the Catalan Government approved the National Pact for Energy Transition [ICAEN-2017].

The way to overcome the resource and environmental crisis is therefore energy transition: the process of progressively replacing fossil and nuclear energies that are contaminating and non-renewable with energy that is clean and renewable. Table 1.3 presents some data that highlights the urgency of the energy transition in Catalonia, Spain and Europe.

Table 1.3 Relation between population, GDP, energy uses and fossil fuel costs						
2014	Population	GDP per capita	Fossil fuel consumption	Energy consumption	Cons/Prod fossil fuels	Fossil fuel costs
	10^6 inhab	€/(inhab·yr)	MWh/ (inhab·yr)	MWh/ (inhab·yr)	%	milions €[1]
World (among countries)	7.265	7.930	14,20	17,86	100,0 %	±1.690.000
OECD	1.270	28.650	32,15	40,46	70,8 %	-845.500
Non-OECD	5.995	3.540	10,43	13,06	120,8 %	+845.500
Europe EU28	505	27.320	22,18	33,12	28,0 %	-447.900
Spain	46,8	22.420	19,34	26,44	2,1 %	-50.500
Catalonia	7,5	27.670	20,10	30,78	1,8 %	-8.000

[1] These values refer to 2012 when the cost of fuels was high; The positive values are income and the negative values payments. Sources: Energy [IEA-2016]; GDP [IMF-2017]; fossil fuel costs [IndexMundi-2017]; data on Catalonia [Idescat-2017a]

Although the energy transition is vital worldwide, it is particularly important in Europe, which imported 72% of the fossil fuels that it consumed in 2014 at a cost estimated in 2012 (when prices were high) of 448 billion euros. Spain imports almost 98% of the fossil fuels it consumes at a cost of 50.5 billion euros, and Catalonia imports all the fossil fuels it consumes at a cost of 8 billion euros.

Although the energy transition to 100% renewable sources is possible and advantageous in the future, a great effort is required by all to change attitudes and ways of proceeding. At the same time, a major transformation is required in the technical, management and governance systems of current human civilisation. The low cost, convenience and patterns of behaviour that fossil fuels have enabled, as well as the resistance to change in the current energy system to maintain its privileges, are obstacles that must be overcome.

1.1.5 Energy transition, population and territory

From a spatial perspective, the most significant characteristic of the current energy model, and by extension of the predominant economic model, is the enormous distance between production and consumption, or translated into spatial terms, between countryside (or rural area) and city (or urban area).

In 2005, the world urban population exceeded that of rural areas for the first time. In 2014, the world urban population was 54% of the total [UN-2014]. A majority of urban dwellers is already evident in North America (82%), South America and the Caribbean (80%) and Europe (73%), with figures above average for Spain and Catalonia. In contrast, in Asia and above all Africa, the urban population has not reached the threshold of 50%, but will do soon. The United Nations [UNH-2016] predicts that by around 2050, two thirds of the world population will be urban: 10% in megacities of over 10 million inhabitants, 35% in cities of between 5 and 10 million inhabitants (the Barcelona Metropolitan Area fits into this category) and the largest percentage, 55%, in medium-sized cities of less than 500,000 inhabitants.

In UN reports drawn up twenty years ago, cities were considered the problem, whereas in more recent studies they are defined as the solution [Kimmelman-2016]. Worldwide, cities contribute 70% of emissions and consume 75% of the resources (the problem and the image of plundering and aggression), but they also produce 80% of world GDP and, more importantly, only occupy between 2 and 3% of the world's surface, 4.6% of Europe [Eurostat-2017] and 6.5% of Catalonia [Idescat-2017b]. Therefore, the concentration of the population in cities protects the planet's land, resources and life. This new urban outlook brings with it a range of major challenges in development, governance and sustainability. Nevertheless, the territorial consequences of the current economic model or the territorial changes required to make it sustainable are not described in the reports.

Today, both the energy system and urban and territorial planning reflect a global economic model based on stocks. Production and consumption take place in separate areas, connected by transport infrastructure that uses substantial amounts of fossil fuels. Much of the energy consumption is associated with this spatial organisation. Policies and management that focus independently on areas of production or consumption further deepen this separation [Wiskerke-2016].

In the past, the introduction of activities in a territory (flows of energy, water, goods and food, as well as waste treatment) and the need for economic growth justified the irreversibility of fossil fuel consumption with the resulting emissions, despite their energy inefficiency, environmental consequences and negative impact on health.

With the current economic model and its spatial organisation based on energy resources that were cheap up to now, including oil and coal, it is very difficult to make the energy transition. Initial policies focused on rationalisation of consumption have had little effect, due to the massive increase in consumption in developing countries (such as China and India). In fact, there are no studies or data that relate production and consumption with the territory or planning in this respect.

While much of the energy consumed in the last 150 years was from underground sources, in the near future is will have to be produced on the surface. Knowledge of current renewable energy systems can be used to predict the surface area that will be required for production, but its impact and implementation will depend on the model that is adopted.

If production remains concentrated in just a few places, the territorial impact will be enormous, and we will not be prepared. In contrast, if energy is harvested continuously and locally in the entire territory, the impact will be more distributed. The concentration of the population in medium-sized urban areas, and the heterogeneity towards which the new territorial planning, and indeed nature, are inclined will favour gradual implementation. An urban focus is essential.

The most recent models of urban metabolism that interpret the city as a living organism, and studies of the circular economy, seek to invert the trend by supporting local or regional action based on shorter, more balanced loops that link all parts and processes [EEA-2015]. These models promote the energy transition, generate sustainable growth to the benefit of the local economy, and facilitate adaptation to the consequences of climate change. All of them are based on a shift from global scale to regional or urban. From a technical and economic perspective, the local scale enables the gradual replacement of current non-renewable energies by renewable energies.

Finally, the landscape is not outside the laws of thermodynamics. Science in general, and thermodynamics and applied ecology in particular, are the basis for the spatial design of the *transition to a new energy model* [Stremke-2011].

1.1.6 Agreements for an energy transition

For some time, there have been indications that we are going through a change in era in terms of the limits of the natural system that sustains us (resources, energy, biodiversity, environmental impact and climate change) and the opportunities provided by the technological developments of recent decades. A new world is struggling to emerge, while an old world fears change.

In recent years, highly relevant initiatives and agreements to drive this change and the energy transition in the world, Europe and Catalonia have gained momentum. Some of the main ones are listed below.

Sustainable Development Goals (September 2015)

In 2000, a total of 189 UN member countries agreed on the Millennium Development Goals (MDG) for 2000 to 2015. These were eight development proposals focused on social problems. The following were particularly notable:

Goal 1. Eradicate extreme poverty and hunger

Goal 7. Ensure environmental sustainability

Goal 8. Develop a global partnership for development

After an assessment of the progress made in the MDG, on 25 September 2015, a total of 193 countries made a commitment in the framework of the United Nations to some new Sustainable Development Goals (SDGs) that would be valid from 2015 to 2030. The MDG had centred on developing countries and on the social agenda. In contrast, the SDG are aimed at all people and all countries. The new goals, which have increased to 17 and have a wide scope, consider in an interconnected way the elements of the social agenda, the environment and economic development. The following goals are notable. Some of them were covered in the MDG, while others are new:

Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Goal 3: Ensure healthy lives and promote well-being for all at all ages

Goal 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

Goal 6: Ensure availability and sustainable management of water and sanitation for all

Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all

Goal 12: Ensure sustainable consumption and production patterns

Goal 13: Take urgent actions to combat climate change and its impacts.

It is the first time that such a broad, global agreement has been made.

Paris change agreement (December 2015)

The twenty-first United Nations Climate Change Conference (also known as the Conference of the Parties, COP21) of the Framework Convention on Climate Change was held in Paris in December 2015. At this event, the first universal agreement was made, approved by 196 countries.

The agreement, which will be effective from 2020, became legally binding in 2016 after its ratification by over 55 countries that emit over 55% of the greenhouse gases (including the USA and China, which are responsible for 40% of emissions).

The key points in the agreement are:

- The increase in the Earth's average temperature at the end of the twenty-first century must be restricted to below 2°C, compared to the pre-industrial level. All countries must contribute to limiting greenhouse gas emissions, if possible so that the temperature increase does not exceed 1.5°C.

- The main instrument of mitigation is either national contributions or emissions reduction plans that will come into force in 2020. These plans have already been presented by 187 counties and will have to be revised with greater reductions every five years.

- The agreement is binding, but the national emissions reduction targets are not. Although penalties are not envisaged, there is a transparent monitoring mechanism to ensure compliance with the agreement.

- The agreement takes into account that developing countries will find it harder to limit emissions than developed countries. It also seeks a balance between emitted gases and those that a country can absorb, with the target of zero net emissions from 2050.

- Developed countries must contribute to funding developing countries with at least 100 billion per year from 2020 onwards; this figure must be revised and increased before 2025. Developing countries are invited to mobilise resources.

The sum of the commitments that have been presented by countries on emissions reduction is not consistent with limiting the increase in average temperature of the Earth to 2°C. Therefore, there are very serious objections about the effectiveness of the COP21 agreements. However, the extent and unanimity of this agreement is raising awareness around the world, which is a highly positive result.

Relation between emissions and reserves

The 2015 Paris Agreement has encouraged many researchers worldwide to study the relationship between the acceptable greenhouse gas emission limit and the existing fossil fuel reserves. One notable study is by Ch. McGrade and P. Ekins [McGrade-2015], entitled *The geographical distribution of fossil fuels unused when limiting global warming to 2°C*, which was published in the journal Nature, and concludes:

- Globally, a third of oil reserves, half of gas reserves and over 80 per cent of current coal reserves should remain unused to meet the target of 2°C.
- The development of resources in the Arctic and any increase in unconventional oil production are incommensurate with efforts to limit average global warming to 2°C.
- Policy makers' instincts to exploit rapidly and completely their territorial fossil fuels are, in aggregate, inconsistent with their commitments to this 2°C temperature limit.

The convergence of these two situations (complete agreement in COP21 to limit the temperature increase to 2°C, and studies on the fossil fuel reserves that should not be used to achieve this) has led to some disinvestment in fossil fuels.

In some parts of the world, energy transition initiatives are beginning to emerge that consider renewable energies as an alternative and that normally establish 2050 as the deadline for completing the transition.

Europe on the path to energy transition (November 2016)

In 2007, the European Union established a set of measures (also known as the 20-20-20 Strategy) with three basic objectives on climate and energy for 2020: reduce greenhouse gas emissions by 20% compared to 1990 levels, increase up to 20% the renewable energies in the energy mix, and improve energy efficiency by 20%.

On 30 November 2016, the European Commission approved what is known as the Winter Package [UE-2016] that, under the slogan *Clean Energy for all Europeans: unlocking Europe's growth potential*, established new targets for 2030: cut emissions by at least 40% with respect to 1990, increase renewable energies up to over 27%, and improve energy efficiency by 30%.

Some aspects of the Winter Package are contradictory (the 27% renewable energies target is very low, half that of the previous decade, and inconsistent with the goal of cutting emissions by 40%), and it maintains the privileges and unnecessarily extends the life of non-renewable energies. However, this set of legal measures does have some positive aspects.

One of them is that, for the first time, the same legislative package presents together the targets of energy efficiency, promotion of renewable energies and CO_2 emissions cuts.

Another positive aspect is the empowerment of the consumer and, above all, recognition of the rights of the producer-consumer. In contrast to Spanish Royal Decree 900/2015 that imposed the "sun tax", the European proposal defends self-consumption. Specifically, it establishes that member states must guarantee the following rights for self-consumers of renewable energies, individually or through aggregators: the right to self-consumption and sale of any surplus renewable energy that is produced, without disproportionate procedures or charges that do not reflect the costs, the right to maintain rights as consumers, the right not to be considered energy suppliers if they do not exceed 10 MWh/year (homes) and 500 MWh/year (legal entities), and the right to receive payment for renewable energy fed into the grid that reflects the market value.

National Agreement for the Energy Transition of Catalonia (January 2017)

The National Agreement for the Energy Transition of Catalonia [ICAEN-2017] arose from the need to generate dialogue between all political powers and civil society representatives to agree on a new, clean, decentralised, democratic and sustainable Catalan energy model, based on renewable energies and in line with the energy objectives of the European Union.

The background document approved by the Government of Catalonia for presentation in the Parliament of Catalonia was the result of a negotiation process, undertaken with the participation of the Council of Entities from economic, social and energy sectors (including the Universitat Politècnica de Catalunya), the Council of Political Parties, and Government of Catalonia ministries associated with the energy sector.

The key points in the National Pact are: guarantee the basic right of access to energy; guarantee energy supply in Catalonia, and the quantity, quality and reliability of this supply; achieve maximum energy saving and energy efficiency; maximize the use of local renewable energy sources; promote energy research and innovation; democratize energy and promote the participation of society in the new energy model; and exercise full competences in the field of energy within the framework of the EU.

Although Catalonia lags behind in the implementation of renewable energies, the launch of a participative process in the National Agreement for the Energy Transition could encourage the general public and organisations to make up for lost time. In addition, local governments have introduced initiatives relating to the energy transition: specifically, Barcelona Metropolitan Area and various towns.

1.2 Responsibilities and opportunities of the UPC

1.2.1 Initiatives for a new energy model

Humanity is facing a major change that consists in the transition from a civilisation based on stock energy resources (fossil fuels and uranium) that enable intense growth while stocks exist, to a civilisation based on energy from flows (renewable energies, solar radiation, water currents and waterfalls, wind), which do not allow such intense use of energy, but have no time limit on the human scale.

To make this transition, we must have a good understanding of the causes and consequences of the crisis, and prepare current and future generations for the new situation we will experience. Two centuries ago, we started on the same path in the other direction: from an economy based mainly on energy from flows (solar radiation and its derivatives) to an economy based on energy from stocks (coal, followed by oil and natural gas), which encouraged the illusion of constant growth. Now we have to turn around. Despite the magnitude of the challenges, we are supported by knowledge and technology that are greatly superior to those of two centuries ago.

Universities are in an excellent position to make a vital contribution to this transformation. Their mission is to teach and transmit knowledge. They are also outstanding repositories of collective knowledge, and drivers of research and predictive studies. Finally, their specific characteristics demand intellectual rigour and neutrality, which should be accompanied by an attentive, critical attitude.

The main objectives of universities are training, promotion of knowledge, scientific progress and technological development. However, given the magnitude of the challenges in the energy transition, this dimension of universities must be smoothly coordinated with two other dimensions: society (conviction, good intentions, civic engagement, as well as production and service activities) and policy (strategy, regulatory framework, economic policy, governance and transactional agreements). Therefore, universities today must strengthen actions focused on their own objectives, and coordinate them with social and policy actions.

The role of the university could be particularly relevant in providing elements of analysis and perspective for social action, and in defining actions of the production system and political action in a context beyond the short term that often absorbs other stakeholders.

The UPC has a long tradition of involvement in energy issues, evidenced by the existence in the past of an experimental nuclear reactor in the Barcelona School of Industrial Engineering (ETSEIB); the creation of the Energy Campus, an active agent in the process of transforming the energy sector; and participation in KIC InnoEnergy, one of the leading knowledge and innovation communities promoted by the European Institute of Innovation and Technology (EIT).

The principles behind this document are:

A holistic view

With the security provided by the short-lived abundance, availability and low cost of energy in a system based on stocks of fossil fuels, society in general and universities in particular have focused on niches of interest and have neglected more general, holistic views.

Therefore, a first step in this project must be to share knowledge and construct a new, holistic view of the alternatives. We must promote work in multidisciplinary teams, focused on challenges beyond the members' own specialisations, with knowledge of the work of other experts and the creation of synergies between fields.

Promotion of cooperation

The system based on fossil energies has driven the trend of prioritising technical solutions over the dynamics of the natural environment of which we form part. Coexistence with other living beings has been overlooked, which leads to loss of biodiversity and has a direct impact on society.

In contrast, the new project must promote respect and knowledge of our natural and social environment, and foster cooperation with natural systems and a fairer society.

Our students' efforts during their education (hours of analyses of calculations, designs and implementation) could be taken advantage of and reinforced by the service-learning method. This consists in guiding students' efforts to give something back to society, solve real problems while they learn, which generally leads to deeper, more mindful learning, and offer these solutions to society altruistically. A commitment to service-learning is a responsibility that the UPC has already assumed.

Work with local resources

Fossil and nuclear resources are concentrated and distant (from Catalonia), which has led to the construction of vast infrastructure and the creation of big companies. University actions have been dominated by these large, distant systems.

In contrast, the new sources of renewable energies (solar radiation, water currents, waterfalls, wind and biomass) are more widely distributed and more local. The new project must highlight the value of local resources and cooperation with the immediate environment. In addition, it must promote the democratisation of knowledge, access, governance and wealth that are derived from the use of renewable energies.

Involvement of all

It would be a mistake for universities to limit their dedication to renewable energies and sustainability to certain lecturers, subjects or managers. In fact, this could have the opposite effect. It could lead to perceptions among the rest of the university community (and society) that the area is specialised and hence not their responsibility or concern.

The project of the *transition to a new energy model* must be addressed with the participation of the entire university community, including lecturers, students and service professionals. It must have an impact on all education activities and all subject areas, so that sustainability becomes as inherent and cross-cutting in technologies as mathematics. Thus, a project will only be deemed complete when all its impacts have been studied and considered in its design, implementation and operation.

The spirit of initiative

The increasing complexity of technical systems in recent decades and the decrease in job prospects have tended to foster passive attitudes. Active, imaginative, challenge-based learning must be promoted, so that solutions can be devised that go beyond short-term answers to problems. To achieve this, we must promote initiative, entrepreneurial spirit and creativeness in students, teaching and research staff and administrative and service staff.

The new project must also encourage future generations to believe in their own capabilities and in the results of their own actions. The new energy system requires more attention and more initiative, and this will promote a more equal distribution of work and wealth.

Therefore, the activities of the Universitat Politècnica de Catalunya and its members could be focused on the following cross-cutting actions:

1.2.2 Train current and future generations

Universities' first main function is to train their students. Due to the nature of higher education, universities are involved in the training of most future leaders and influence their values. Our students will become professionals and team leaders whose work will have a profound impact on society. Each year, around 5,500 students graduate from the UPC, and go on to work for around 35 years. In other words, every year we generate 192,500 years of professional work by highly qualified professionals, many of whom are responsible for teams and set trends. It is therefore essential that our students are aware of the real problems in the world and the solutions that they could incorporate into their work. As an example, the MIES report of 1999 [Cuchí-2005] suggested that just the 100 graduates a year from the Vallès School of Architecture (ETSAV) would be responsible throughout their professional life for buildings that could generate 2.25

million tonnes of CO_2. If these students are educated in all aspects of sustainable methods, the impact on society will be enormous.

The crisis of non-renewable energy resources (like that of other scarce resources) and its impact on society and the environment is probably the main problem that must be faced in coming decades. The *transition to a new energy model* is no longer just an option; it is becoming a question of survival. However, choices do exist in the way we make this transition. Faced with the crisis in the non-renewable energies that support human activity today, the Universitat Politècnica de Catalunya must launch a *general education project* on present and future sustainability. This must be designed for the entire institution to:

- Introduce sustainability and the energy transition as an essential part of all subjects on all UPC courses.
- Strengthen UPC students' confidence in their own abilities to come up with local solutions that help to attain sustainability and the energy transition.

1.2.3 Advance research

The aim of basic research is to progress in knowledge, whilst advanced researched is focused on developing the conditions for applying knowledge. In general, universities are strongly commitment to research activities, and technical universities such as the UPC are particularly committed to applied research.

The schools and faculties of the Universitat Politècnica de Catalunya, and their departments, centres and related research groups, are competent in knowledge and technologies that have a direct impact on the new energy model. Indeed, the Barcelona School of Agricultural Engineering (ESAB) is associated with food; the two architecture schools and the School of Building Construction (EPSEB) with habitability; the five schools of industrial engineering and the Barcelona School of Civil Engineering (ETSECCPB) with physical accessibility; the two schools of telecommunications and the Barcelona School of Informatics (FIB) with virtual accessibility and the increasing use of information and communication technologies (ICT); and all UPC centres, above all the engineering schools, with technological processes and the new energy system.

This potential of the UPC must be strengthened and put at the service of the surrounding society. To achieve this, we propose three basic actions:

Pool knowledge

One of the benefits of the *process of meeting and discussion* that led to this background document was that it revealed the number, quality and interest of the initiatives, studies and research areas that are being undertaken at the UPC in the fields of energy and sustainability. However, the process also highlighted that most of these initiatives require more general analyses.

To follow-up the process of meeting and sharing knowledge, the background document should be revised every 4 years, to update the analysis and the future areas of work of the UPC over time.

With the security of abundant and, until recently, cheap non-renewable energy resources, society in general and universities in particular have tended to focus on niches of interest in the short term, and have overlooked more general, long-term perspectives.

Within the UPC, it is essential to build shared knowledge from the perspective of the *transition to a new energy model*. One first step in this transition consists of together creating a new, holistic view of the situation and the alternatives.

Strengthen current research areas

The process of collective reflection highlighted research that is being undertaken at the Universitat Politècnica de Catalunya in line with the project of *transition to a new energy model*. The University's governing bodies must recognize these initiatives, disseminate and strengthen them. Relevant tasks include:

- Provide continuity to the project of *transition to a new energy model*.
- Strengthen the role of the Energy Campus. Campus of International Excellence within the UPC.
- Take advantage of synergies with the Institute for Sustainability and the European project KIC Innoenergy.
- Strengthen groups whose research is associated with the *transition to a new energy model.*
- Strengthen research groups that study the generation of low power technology or dematerialisation (how to replace processes that require many resources with others that require fewer).

Promote new strategic areas of research

In a holistic analysis of the current crisis and future alternatives, some topics or technologies have emerged that are of great strategic importance, but are not currently studied at the UPC.

It is essential to assess these gaps, analyse the strategic value for the UPC and its surrounding environment, and, if appropriate, encourage with incentives and resources the creation of research groups to focus on these areas.

Strategic areas in which gaps have been detected are:

- Engineering of biosystems that are more efficient at harvesting and transforming energy.
- Studies on the evolution of resources and energy uses.
- Reviews of technological processes, particularly industrial processes, to save energy.
- Research on energy storage, particularly electrical energy.
- Territorial studies to establish criteria on the occupation of spaces for harvesting energy.

1.2.4 Test new solutions

Universities in general, and the Universitat Politècnica de Catalunya in particular, have extensive experience in testing solutions.

The *transition to a new energy model* involves progressing towards a new situation. We have knowledge of some associated aspects and technologies (such as hydroelectric, wind, photovoltaic and biomass power), but we still have limited experience of the consequences of their technological and social implementation on a large scale in an energy system:

- How will the new renewable systems behave over time?
- How can we manage their intermittent, random nature?
- How will the population react to these changes?
- What technologies and social behaviours will emerge with greatest force?
- What alternative processes can be used that are less costly in energy terms?

The Universitat Politècnica de Catalunya should play a central role in testing these new solutions in Catalonia. It has a responsibility as an institution funded with public resources, it is in a strong position from a technological and social perspective, and it has good opportunities to participate. There are two main areas in which it can get involved:

Collaboration with the environment

This is an area that has emerged strongly in recent times: collaboration with the production system, governments, government bodies, associations and civil society.

The university contributes some of its specific values to this collaboration: constant revision of knowledge bases; methodological rigour in its work; connection of research with innovation; a more integrative, long-term perspective.

At a time of systemic crisis such as the current one, the specific values that universities contribute could be key to the proposals, monitoring and evaluation of the social experiments that must be undertaken to implement the new energy and social model.

Testing in its own context

The Universitat Politècnica de Catalunya is a very complex organisation with 5 campuses (3 in Barcelona, 1 in Terrassa and 1 in Castelldefels), located in 8 municipalities (Barcelona, Terrassa, Manresa, Vilanova i la Geltrú, Igualada, Sant Adrià del Besòs, Sant Cugat del Vallès and Castelldefels), 15 schools and faculties, around 60 buildings, 2,400 lecturers, 1,600 service professionals and 32,000 students.

Therefore, the University itself could be the site of pilot schemes with the following objectives:

- Boost the energy saving programme that is already being implemented in UPC buildings and take a further step by testing new solutions.
- Take advantage of roofs and other spaces to test new concepts and systems for generating renewable energies, particularly solar thermal, photovoltaic and wind power.
- Test energy storage systems. Specifically, experiment with the installation of a pilot electricity-hydrogen-electricity plant in the University.
- Reconsider open areas of the campus to support energy harvesting and storage systems.
- Work on sustainable mobility for the University's 36,000 members to access the facilities.
- Introduce new experiences in bar and restaurant activities, particularly in relation to packaging.
- Monitor opinions in the university community about changes caused by previous actions.
- Replace processes that use substantial amounts of energy and resources with others that are more sustainable.
- Optimise and manage ICT resources to reduce consumption.

Some of these schemes, which will be experienced directly by many future leaders and will have an impact on families, could be key to bring about progress in all society. Testing at the UPC could be extrapolated and lead to the transfer of technology and behaviour to other contexts in the surrounding environment.

1.2.5 Participate actively in the general debate

The Universitat Politècnica de Catalunya plays a key role in Catalan society. Its statements, particularly if they are of a collective, institutional nature, could become a point of reference for all society and help to foster the energy transition.

Therefore, the Universitat Politècnica de Catalunya wishes to participate actively in the general debate on the new energy model and the social transformations that it involves, and to draw up proposals for the energy and social transition.

Consequently, the UPC aims to be present and active in:

- The National Pact for Energy Transition of Catalonia and all related areas in which the UPC's contribution and involvement could be useful.
- Commissions and areas (professional associations, as well as standardisation, regulatory and legislative bodies) in which proposals relating to the energy transition are made and evaluated.
- Forums of discussion, talks and media that deal with topics relating to the *transition to a new energy* model, in the national and international arena.

2. Food and energy

Contents

2.1 Analysis of the situation and trends

The transformation and preservation of food resources is a constant challenge to produce quality food in sufficient quantities, safely, sustainably and at a low cost. European strategy establishes as a priority the reorientation of the production sector to fit a smarter, more sustainable, more integrative economic model.

To face this challenge, an effort is required to increase scientific and technological knowledge. Clearly, a lot of information is available, but a lot of training is required to apply it and to enhance society's knowledge.

Eating is the most basic function of humans. Food is required for the construction and renovation of the body's biological structure and for the supply of energy needed to perform vital functions. In addition to water, food must contain sufficient amounts of proteins, fats, carbohydrates, vitamins and minerals. Foods that are consumed by humans come mainly from organic matter from primary producers (plants) and primary consumers (animals) in the food web. The energy they contain comes from solar energy, captured through the process of plant photosynthesis. Humans are omnivores (they eat both plant and animal products), which means they can adapt to many circumstances.

The basal metabolic rate of an average adult human (at rest) is around 80 W (1.9 kWh/day) and the average additional energy needed for everyday activities is around 40 W (1 kWh/day). Therefore, the total energy required is around 120 W (2.9 kWh/day or 2,500 kcal/day [kilocalories per day]). This energy flow, multiplied by the 7.266 billion people on Earth in 2014, gives a total food energy demand of 7,640 TWh per year, which is 19.4 times less than the primary energy produced by the anthropogenic energy system at 148,100 TWh per year.

All the endosomatic and exosomatic energy that we use comes from, or has come from, the sun, except for energy from nuclear fusion. The new energy models must be more efficient at capturing energy flows through the Earth's ecosystem.

2.1.1 The food supply chain

Today, most food is obtained from crop cultivation and livestock farming; hunting and gathering are increasingly marginal activities. Globally, aquaculture in 2014 provided more than half of aquatic animal products (including fish) for direct consumption. In the current industrialised society, the food supply chain or agri-food system has become highly complex. The complete chain includes primary production sectors (agriculture, livestock farming, fishing and aquaculture), the food processing industry, the distribution and consumption of foods, and the management and treatment of solid and liquid waste, which must be designed to recover nutrients and energy and close the cycles. This chain is illustrated in Figure 2.1.

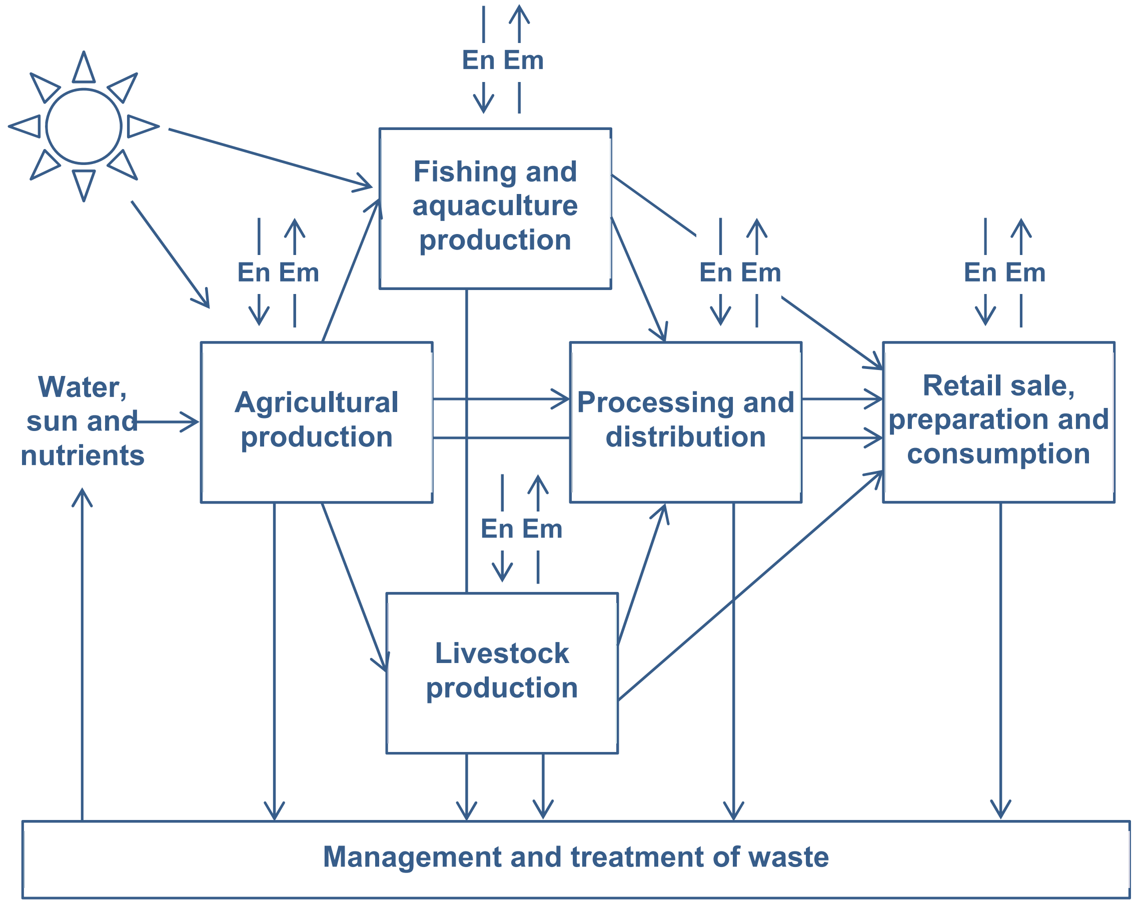


Figure 2.1 Diagram of the sectors of activity in the human food chain (En = energy; Em = emissions). Compiled by: X. Flotats

The structure of the food chain in Figure 2.1 depends on the distribution of consumption. In small rural towns, the raw materials are produced in the surrounding areas and the distribution is relatively simple. In large cities, which are currently inhabited by over 50% of the world population and over 70% of the European population, the complexity of the food chain becomes evident. Rural areas where much of the food is produced are separated spatially from urban areas where there is a high density of consumption, and higher energy costs are needed to maintain flows of food and waste transformation.

The food supply chain includes activities in the three main economic sectors:

Primary activities and products: agriculture, livestock farming, fishing and aquaculture. Agriculture provides products of plant origin; livestock farming, fishing and aquaculture produce products of animal origin.

Secondary activities: food and drink industries. These cover all the processing, preparing and packaging of primary products to create a wide range of processed food products (including meat products and derivatives such as cold meats, wines and cavas, bread, pastries and desserts, juices and non-alcoholic drinks, oils and fats, dairy products and derivatives, fruit and vegetables and precooked products), and all the processes and packages for preservation and distribution.

Tertiary activities: activities of retail, preservation close to the place of consumption, food preparation and cooking in people's homes and in the catering sector, including bars and restaurants.

2.1.2. Food, energy and emissions

Globally in 2009, the activities of the food supply chain, excluding energy incorporated by plants from solar radiation and the function of chlorophyll, accounted for 30% of final energy consumption in the human energy system, and generated 20% of anthropogenic greenhouse gas emissions [FAO-2011a].

Notably, developed countries (OECD), which have only 18.1% of the world population, use more than half of this energy (13,890 TWh/year, 52.6%), while the rest of the countries (non-OECD) with 81.9% of the world population use just under half (47.4%). Therefore, the per capita energy consumption in the food supply chain is very uneven: 11,340 kWh/(inhabitant·year) in OECD countries and only 2,260 kWh/(inhabitant·year) in non-OECD countries, when the world average is 3,900 kWh/(inhabitant·year).

World energy use in the human food chain is distributed as follows (Table 2.1, [FAO-2011a]): primary production, 21.9%, which is the smallest part (agriculture, 12.9%; livestock farming, 6.4%; and fishing and aquaculture, 2.5%); processing of primary products, 43.3%; and the distribution, preparation and cooking of food, the remaining 34.9%. The percentage of energy use for processing and distribution is higher in OECD countries (almost half of the energy), while the percentage of energy consumption for the preparation and cooking of foods is higher in non-OECD countries. Primary activities account for between 19.5% (non-OECD countries) and 24.0% (OECD countries) of energy use. These data are not available for the EU28, Spain or Catalonia.

Table 2.1 Energy uses and emissions in the energy supply chain

2009	Energy						Emissions	
	WORLD		OECD		Non-OECD		WORLD	
	TWh/yr	%	TWh/yr	%	TWh/yr	%	$GtCO_{2eq}$/yr	%
TFC-TOTAL	88.460		37.600		50.860		49,00	
TFC-food	26.390		13.890		12.500		9,70	
% TFC-food/TFC-total	29,8 %		36,9 %		24,6 %		19,8 %	
Primary production	5.770	21,9 %	3.330	24,0 %	2.440	19,5 %	6,35	65,5 %
Agriculture	*3.410*	*12,9 %*	*1.600*	*11,5 %*	*1.810*	*15,5 %*	*2,76*	*28,5 %*
Livestock	*1.690*	*6,4 %*	*1.250*	*9,0 %*	*440*	*3,5 %*	*3,40*	*35,0 %*
Fisheries and aquaculture	*670*	*2,5 %*	*480*	*3,5 %*	*190*	*1,5 %*	*0,19*	*2,0 %*
Processing and distribution	11.420	43,3 %	6.670	48,0 %	4.750	38,0 %	1,65	17,0 %
RS, preparation, cooking	9.200	34,9 %	3.890	28,0 %	5.310	42,5 %	1,70	17,5 %
	kWh/ (inhab·yr)		kWh/ (inhab·yr)		kWh/ (inhab·yr)		tCO_{2eq}/ (inhab·yr)	
Per capita	3.900		11.340		2.260		1,43	

TFC = Total Final Consumption; Em = Emissions; RS = Retail Sale; Gt = gigatonnes = billions of tonnes; CO_{2eq} = other greenhouse gases (methane, NO_x) converted to CO_2 equivalent. Sources: [FAO-2011a], [IPCC-2015]

Food supply chain activities account for 19.8% of greenhouse gas emissions. These are mainly concentrated in primary activities (65.5%), particularly livestock (35.0%) and agriculture (28.5%). The rest of the GHG emissions are distributed in almost equal parts between industrial processes and food preparation and cooking.

According to the Intergovernmental Panel on Climate Change (IPCC) [IPCC-2015], annual anthropogenic greenhouse gas emissions in billion tonnes of CO_2 equivalent are 49 $GtCO_{2eq}$ distributed as follows: 31.8 $GtCO_{2eq}$ of CO_2 from fossil fuels and industrial processes; 5.4 $GtCO_{2eq}$ of CO_2 for changes in land use; 11.8 $GtCO_{2eq}$ of methane, NO_x and fluorinated gases. Agricultural and livestock farming activities emit or cause much of these latter gases.

As well as consuming 30% of human energy systems and generating 20% of greenhouse gas emissions, food supply chain activities use most of the land that has been transformed by humans (approximately 10% of landmass is used for crops and 20% for pastures), exploit most of the fishing grounds of oceans, seas, lakes and rivers, and use over 70% of fresh water.

2.1.3. FAO food balance sheets

For several decades, the FAO have complied food balance sheets for countries and geographic areas [FAO-2016]. Figure 2.2 shows the food balance sheet as a diagram.

The first part takes primary production (agricultural: cereals, roots and tubers, vegetables, fruit and others; livestock: meat, milk, eggs; fishing and aquaculture: fish, crustaceans and algae); added to imports/exports and adjusted to changes in stocks to give the food supply, that is, what is consumed by the country or geographic area. Then, the supply is divided into different uses: seed reserves, animal fodder and feeds, wastage due to the manufacture of processed foods or other reasons, non-food uses (tobacco, fibres, rubber, biofuels) and the part that is strictly speaking allocated for human food (Figure 2.2).

The second part of the food balance sheet is based on the supply of foods and assesses their contribution to vital functions; specifically their calorific value (kcal/(inhab·day)), kilocalories per inhabitant per day), the proteins they provide (g/(inhab·day)), grams per inhabitant per day) and fats (g/(inhab·day)).

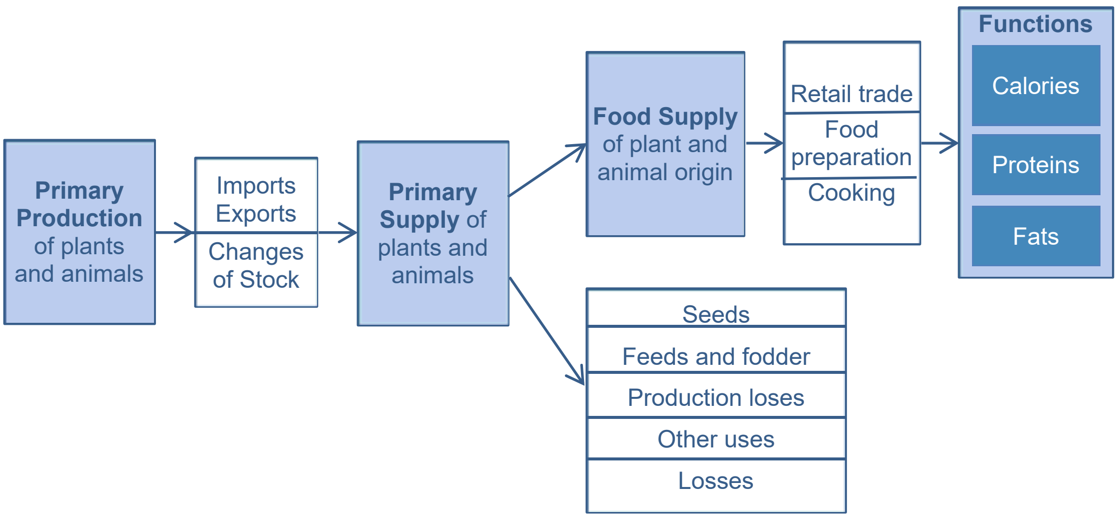


Figure 2.2 Diagram of an FAO food balance sheet

First part of food balance sheets

In 2011, primary production in the world, which is the basis of human food (Table 2.2), stood at 12,531 Tg/year (teragrams or millions of tonnes per year; 1,820 kg per inhabitant per year) of which 11,197 Tg/year (89.4%) was of plant origin and 1,334 Tg/year of animal origin.

This primary production was distributed as follows: 33.6% fodder and feeds; 17.0% wastage in the manufacture of processed products; 12.4% seeds and losses; and the remaining 37.9% (4,727 Tg/year, 686 kg/(inhab·year)) for what is strictly speaking human food. A total of 86.7% of animal products end up transformed into human food, while only 32.1% of plant products become human food.

Compared to 1961 (50 years previously), world primary production has multiplied by 3.13 and the food supply by 3.12, while the population has multiplied by 2.25. Consequently, the per capita food supply increased by 36.8% from 495 to 686 kg/(inhab·year). In the primary supply the proportion of plant products is close to 90%; in the food supply it is approximately 75%, and there have been no significant variations since 1961. In 2011, only 37.9% of the world primary supply became food supply; with a lower proportion of plant matter (32.1%) and a much higher proportion of animal matter (86.7%).

Table 2.2 World: from primary production and supply to food supply

World FAO: food balances	Primary production		Primary balance	Primary supply		Feed and fodder	Other[1]	Food supply
	Tg/year	%	Tg/year	Tg/year	%	Tg/year	Tg/year	Tg/year
1961 (population: 3.056,2 million inhabitants)								
Total products	4.009	100,0%	-25	3.984	100,0%	1.449	1.022	1.513
% primary supply	100,6%		-0,6%	100,0%		36,4%	25,7%	38,0%
Plant products	3.515	87,7%	-19	3.496	87,8%	1.346	996	1.153
% primary supply	100,5%		-0,5%	100,0%		38,5%	28,5%	33,0%
Animal products	494	12,3%	-6	488	12,2%	103	25	360
% primary supply	101,2%		-1,2%	100,0%		21,1%	5,1%	73,8%
2011 (population: 6.887,3 million inhabitants, 125,4% increase)								
Total products	12.531	100,0%	-56	12.475	100,0%	4.088	3.668	4.727
% primary supply	100,4%		-0,4%	100,0%		32,8%	29,4%	37,9%
Plant products	11.197	89,4%	-56	11.141	89,3%	3.982	3.595	3.571
% primary supply	100,5%		-0,5%	100,0%		35,7%	32,3%	32,1%
Animal products	1.334	10,6%	0	1.334	10,7%	106	73	1.156
% primary supply	100,0%		0,0%	100,0%		7,9%	5,5%	86,7%

Tg/year = teragrams per year = millions of tonnes per year; [1] In the FAOSTAT food balances, it is the sum of the sections on feeds, seeds, wastage, processing and other uses, to which fodder has been added. Source: [Faostat-2016]

Table 2.3 shows the figures for Spain, an example of a developed country whose food supply chain has changed dramatically in the last 50 years:

Table 2.3 Spain: from primary production and supply to food supply

World FAO: food balance sheet	Primary production		Primary balance	Primary supply		Feed and fodder	Other[1]	Food supply
	Tg/year	%	Tg/year	Tg/year	%	Tg/year	Tg/year	Tg/year
1961 (population: 30,74 million inhabitants)								
Total products	61,8	100,0%	-0,3	61,5	100,0%	24,5	13,8	23,2
% primary supply	100,5%		-0,5%	100,0%		39,8%	22,4%	37,7%
Plant products	56,2	90,9%	-0,5	55,8	90,7%	23,3	13,7	18,9
% primary supply	100,7%		-0,9%	100,0%		41,8%	24,6%	33,9%
Animal products	5,6	9,1%	0,1	5,7	9,3%	1,2	0,2	4,4
% primary supply	98,2%		1,8%	100,0%		21,1%	3,5%	77,2%
2011 (population: 46,51 million inhabitants, 51,3% increase)								
Total products	126,1	100,0%	3,9	130	100,0%	58,7	30,7	40,7
% primary supply	97,0%		3,0%	100,0%		45,2%	23,6%	31,3%
Plant products	109,9	87,2%	1,3	111,2	85,5%	56,4	29,8	25,0
% primary supply	98,8%		1,2%	100,0%		50,7%	26,8%	22,5%
Animal products	16,1	12,8%	2,7	18,8	14,5%	2,4	0,9	15,7
% primary supply	85,6%		14,4%	100,0%		12,8%	4,8%	83,5%

Tg/year = teragrams per year = million of tonnes per year; [1] In the FAOSTAT food balance sheets, it is the sum of the sections on feeds, seeds, wastage, processing and other uses, to which fodder has been added. Source: [Faostat-2016]

Between 1961 and 2011, primary food production in Spain doubled (by a factor of 2.04), and primary supply increased slightly more (by a factor of 2.11). The increase in food supply was more moderate (a factor of 1.75), while the population only increased by 50% (a factor of 1.51). These data reveal three trends. First, as primary supply has increased more than primary production, Spain has shifted from a country that exports small amounts to one that imports small amounts. Second, the food supply chain has become less efficient in general: in 1961, a total of 37.7% of the primary supply (33.8% of plant products) became part of the food supply, while in 2011 only 31.3% (only 22.5% of plant products) became part of it. Third, the proportion of food from animal products doubled in these 50 years: from 18.8% in 1961 to 38.5% in 2011.

Second part of food balance sheets

In 2011, the world food supply provided 2,867 kcal/(inhab·day) of average calorific value, 80.2 g/(inhab·day) of proteins and 82.9 g/(inhab·day) of fats; quantities that are more than sufficient for adequate nutrition (Table 2.4). The problem of hunger is due more to distribution than production, as well as the excessive inclination towards animal products in some countries.

Globally in 2011 (Table 2.4), 75.5% of the mass of food was of plant origin and 24.5% was of animal origin. Although it is not shown in Table 2.4, out of the plant products, cereals

(21.5% of the total food) provide 45.2% of the energy and 39.8% of the proteins; oils and oleaginous crops (2.7% of the total) provide 43.3% of fats; vegetables account for 19.8% of the total food and fruits 10.8%. Out of animal products, meat and entrails (6.9% of the total) provide 19.2% of the proteins and 31.0% of the fats, while milk (13.1% of the total) provides 10.2% of the proteins and 9.2% of the fats.

Table 2.4 World: from food supply to vital functions (energy, proteins and fats)

World FAO: food balance sheets	Food supply			Energy		Proteins		Fats	
	Tg/year	kg/ (inhab· year)	% total	kcal/ (inhab· year)	% total	g/ (inhab· year)	% total	g/ (inhab· year)	% total
1961 (population: 3.056,2 million inhabitants)									
Total food	1.513	495,2	100,0 %	2.196	100,0%	61,7	100,0 %	47,5	100,0%
Plant products	1.153	377,3	76,2 %	1.857	84,6 %	41,9	67,9 %	22,8	48,0 %
Animal product	360	117,9	23,8 %	339	15,4 %	19,8	32,1 %	24,7	52,0 %
2011 (population: 6.887,3 million inhabitants, 125,4% increase)									
Total food	4.727	686,3	100,0 %	2.867	100,0 %	80,2	100,0 %	82,9	100,0%
Increase 1961-2011	212,4 %	38,6 %		30,6 %		30,0 %		74,5 %	
Plant product	3.571	518,5	75,5 %	2.359	82,3 %	48,5	60,5 %	45,9	55,4 %
Animal product	1.156	167,8	24,5 %	508	17,7 %	31,7	39,5 %	37,0	44,6 %

Tg/yr = teragrams per year = millions of tonnes per year. Source: [Faostat-2016]

The proportion of foods of animal origin in the diet is closely related with the efficacy of the food system. For example, in the USA, only 22% of the primary supply becomes food (14% of the production of plant origin), while in India 41% becomes food. The amount of animal products in the diet also has an impact on aspects of health.

Table 2.5. Spain: from food supply to vital functions (energy, proteins and fats)

Spain FAO: food balance sheet	Food supply			Energy		Proteins		Fats	
	Tg/year	kg/ (inhab·yr)	% total	kcal/ (inhab·yr)	% total	g/ (inhab·yr)	% total	g/ (inhab·yr)	% total
1961 (population: 30,74 million inhabitants)									
Total food	23,22	755,3	100,0 %	2.633	100,0 %	79,0	100,0 %	67,8	100,0 %
Plant products	18,86	613,4	81,2 %	2.278	86,5 %	52,7	66,7 %	45,6	67,3 %
Animal products	4,36	141,9	18,8 %	355	13,5 %	26,3	33,3 %	22,2	32,7 %
2011 (population: 46,51 million inhabitants, 51,3% increase)									
Total food	40,74	875,9	100,0 %	3.186	100,0 %	103,0	100,0 %	160,4	100,0 %
Increase 1961-2011	75,5 %	16,0 %		21,0 %		30,4 %		136,6 %	
Plant products	25,05	538,5	61,5 %	2.354	73,9 %	37,9	36,8 %	105,2	65,6 %
Animal products	15,69	337,4	38,5 %	832	26,1 %	65,1	63,2 %	55,2	34,4 %

Tg/year = teragrams per year = milions of tonnes per year. Source: [Faostat-2016]

As mentioned above, the proportion of foods of animal origin in Spain has more than doubled in 50 years, from 18.8% to 38.5% (not far from the figure for the USA, which is 41.7%, but dropping). In 2011, Spanish food supply had values higher than the global average: 3,168 kcal/(inhab·day) in calorific value, 103.0 g/(inhab·day) of proteins and 160.4 g/(inhab·day) of fats. This last value is double the global average and 2.37 times that of 1961 (Table 2.5).

As it is not a state, Catalonia is not listed in Faostat and, therefore, does not have published food balance sheets.

2.1.4 Primary food production

Until the start of the twentieth century, agricultural production depended exclusively on the natural fertility of soils and their improvement by applying farm manure, guano or nitrates from mineral sources. The development of the Haber-Bosch process to produce ammonia (NH_3) from atmospheric nitrogen and hydrogen obtained from natural gas, which consumes 31 MJ/kg NH_3 on average, meant that nitrogen fertiliser could be made synthetically. This led to the green revolution of the 1960s, which combined improvements in production technologies with improvements in the genotypes of crops. The crop yield increased by a factor of 4 between 1990 and 2000. In 2010, Smil [Smil-2011] estimated that world annual production of N for nitrogen fertilisers via the Haber-Bosch process stood at 100 Tg/year (millions of tonnes per year), which represents around 4,200 TWh/year and over 99% of the total production of synthetic nitrogen fertilisers.

Loss of nitrogen fertilisers by volatisation, leaching, run-off or soil erosion cuts efficiency to 38-45% [Oenema-2009]. In countries with a high proportion of animal protein in the diet, the transformation of plant nitrogen into animal protein reduces the overall efficiency of nitrogen in the food system to under 15% [Smil, 2011]. All these inefficiencies lead to considerable release of nitrogen into the atmosphere and into surface and underground waters from chemical fertilisation, manure, sludge from wastewater or other treatments of liquid and solid waste from the food industry or municipal waste.

Another essential nutrient for food production is phosphorus. This is a non-renewable mineral, whose annual production was approximately 15-20 Tg P/year in 2000-2010. The main reserves are limited and are in Morocco (in the former Spanish Sahara). At the current rate of consumption, a drop in production rate is forecast for 2030-2040, with an increase in production costs and exhaustion of the reserves in 100-150 years [Foged-2012]. Apart from the geopolitical problems that can be caused by dependency on very localised reserves, the use of this nutrient is characterised by its efficiency as a fertiliser and losses throughout the food chain, and by additional “reserves” that can be obtained from manure and other waste.

Agricultural production and energy

The FAO [FAO-2009] estimates that by 2050 food production must have increased by 75%, to cope with the population growth and ensure nutrition, food quality and food safety for the world population. The challenge that the FAO has highlighted is how to obtain this target with more efficiency and less resources than at present: less agricultural land per capita, less water consumption per hectare, less consumption of fertilisers, less consumption of pesticides and less energy consumption, to reduce the environmental impact of food production, increase safety (health) and tackle climate change.

In addition to these challenges, in terms of energy, food production must be compatible with the production of biofuels on limited land. Biotechnology must play a vital role in meeting these challenges, through traditional genetic improvement and more recent strategies of transgenics or genome editing. It is true that people in some sectors of the population have reservations about biological systems engineering, often due to misinformation. The Universitat Politècnica de Catalunya should contribute to ensuring that this debate is based on solid scientific evidence and not on half-truths.

The improvement in agricultural production in the last 50 years has led to a considerable increase in energy consumption, distributed approximately in 60% to produce inorganic fertilisers, 20% in the use of machinery and 15% to obtain water for irrigation, as the main items [Pimentel-2008a]. In non-irrigated crops, the third most energy is consumed in the manufacture of pesticides.

The main principles for reducing energy consumption in agriculture and moving towards sustainable agricultural systems (SAS) are: a) increase organic matter in the soil to reduce erosion, increase fertility, increase water retention capacity and reduce the need for mineral fertilisers; b) genetically improve crop plants so that they harvest energy and transform it into nutrients more effectively, particularly in low-input environments, c) tend towards more complex agricultural systems and organize production systems (cropping sequence, spatial distribution of crops, biological diversity within the crop) to increase resilience and reduce the energy input into the system (including energy added in the form of pesticides).

Two of the cornerstones of environmental improvement are increasing biological diversity to enhance resilience, and reducing the consumption of pesticides. To achieve this, agricultural tools designed to conserve soil, water and nutrients, as well as technologies to develop precision agriculture, are vital to reduce the input and energy required to produce food [Cañameras-2010]. Suitable agricultural techniques could reduce energy consumption in agricultural production by up to 53% [Pimentel-2008b].

Biosystems engineering is focused on obtaining more energy efficient organisms. A genome editing technique that has already become popular is CRISPER ([Hsu-2014] [Bortesi-2015]). Such techniques will probably help to reduce society’s reservations about the use of genotypes obtained by directed gene modification.

Precision agriculture, which uses technologies to optimise the management of farms according to needs (GPS, satellite images, sensors, management information systems, etc.), can optimize the use of resources to improve efficiency and adapt operations to specific features. For example, the use of machine guidance techniques via satellite for applying fertilisers or pesticides, the use of precision sowing machines, humidity sensors for differential irrigation depending on the soil characteristics and crop periods, among other techniques, could cut energy by at least 15%. In coming years, the energy challenge will lead to the development of techniques that improve the efficiency of agriculture, either to produce more food, or to reduce the wastage of natural resources such as land, water or energy, in any production model, whether it is productivist and intensive or distributed.

Animal production and energy

A wide range of food products are derived from livestock, including dairy products, eggs, and meat, which vary greatly in protein and fat quality. Livestock accounts for 40% of the value of world agricultural production, and provides a livelihood and food security for almost 1,300 million people.

Livestock farming occupies the largest proportion of global land use: pastures and croplands dedicated to the production of feed for livestock represent almost 80 per cent of all agricultural land. Fodder crops are sown in a third of all cropland, while the total surface area of land occupied by pastures is equivalent to 26 per cent of the Earth's ice-free surface [FAO-2017].

Extensive livestock farming is mainly limited by pasture production in a certain region, and therefore a balance is maintained between productive capacity of pastures and undergrowth and the productive capacity of meat and derivatives. In this case, the energy component is of low intensity. In contrast, intensive livestock farming, particularly of pigs and poultry, creates an imbalance that has environmental and energy consequences.

For example, intensive pig farming in Europe is in areas close to sea ports in Denmark, northern Germany, Holland and Belgium (Rotterdam port), Brittany, Catalonia (the ports of Tarragona and Barcelona). This is because these countries do not produce soya or cereals in large enough quantities to feed the livestock that is fattened, so these raw materials are imported from high-production areas, such as the USA, South America and South-East Asia.

Furthermore, intensive farming of livestock and the transformation of animals into processed products requires advanced knowledge of genetics, food and technology to keep the animals in the best conditions, and for their subsequent processing, which adds value and contributes a considerable proportion to the economies of producing countries.

In Catalonia, the livestock sector contributes 63.6% to final agricultural production. The pig sector contributes 55.5% to this total and is clearly an exporter; the poultry and egg sector account for 20.6%; and the cattle and milk sector, 18.9%. Without the intensive model of livestock farming, the production of animal protein would be limited to the capacity of agricultural land to produce plant origin food for humans and feed for livestock simultaneously, and meat would have to be imported if demand was maintained.

The energy consumption of intensive pig and poultry farming has three components: a) energy for agricultural production of components of feeds in distant countries and for their transport; b) energy to maintain suitable environmental conditions for reproduction and growth of animals in barns; and c) energy invested in managing manure from farms. In the second component, heating is the main energy use, with requirements that could reach 0.85 MWh/year per pig in the pig sector.

The challenges to reduce energy consumption in livestock barns include: improving the design of barns to capture passive solar energy, using other renewable energies, controlling air circulation and adopting heat exchangers. In any case, the main challenge will be to reduce dependency on the importation of plant-based raw materials for feed production and the energy consumption associated with this distant agricultural production.

The main environmental implications of intensive livestock farming are due to intercontinental transport of raw materials that are rich in nutrients (nitrogen and phosphorus). Pigs fix around a third of this nitrogen in the form of animal protein, and release the rest in slurry in a relatively diluted form. To recycle this nitrogen as a fertiliser, it must be returned to the agricultural areas that it came from on other continents. This is possible, but the energy costs of concentrating the nutrients would be high. The future challenge of intensive livestock production is to solve the problem created by this imbalance in the intercontinental distribution of nutrients. The waste treatment sector could provide technological solutions to improve the situation, but the livestock sector must also act to optimize the transformation efficiency, improve the design of barns to make them more efficient, reduce the consumption of products from distant places, and solve the problem of inequalities caused by the demand for meat products.

Fishing and aquaculture production

In 2008, the cost of energy consumption by European Union fishing vessels was approximately 24% of the total [Anderson-2010]. The cost of fuel with respect to the sector's revenue varied widely: from 6.3% in the Faroe Islands to 24.6% in Lithuania, with values of 12.4% for Spain [Muir-2015].

Energy costs depend greatly on the fishing equipment that is used and the kind of fish. Fishing with coastal fishing nets (for sardine) and dragnet fishing in deeper waters (for monkfish) have the lowest and highest costs (0.175 and 2.547 tonnes of fuel per tonne of fish captured, respectively), which is in line with their commercial performance. A change in fishing equipment can considerably reduce energy consumption for the same species. For example, it can cut energy consumption in cod fishing by 80%; and energy consumption in flatfish fishing up to 92% [NSF-2017].

According to current studies, actions that could promote considerable reductions in energy consumption in the fishing sector are: introducing more sustainable fishing equipment, changing fishing methods, boosting demand for local species, fishing closer to the coast, and modernising boat equipment and design.

Energy consumption in aquaculture depends largely on the species of fish that are produced and the way they are raised. However, in most cases of intensive farming, the energy consumption associated with fish feed accounts for 75 to 95% of the total, whilst fuel consumption is under 10% [Muir-2015]. The energy cost of feed and that of water treatment (which is often overlooked) may be reduced if the waste from one trophic level (production of one species of fish) is considered a resource for another tropic level. In other words, energy costs will be lower in integrated multi-trophic aquaculture (IMTA).

In short, actions that have a clear impact on reducing energy consumption in the aquaculture sector include: improving the feed conversion ratio, diversifying the raw materials used in feed production, reducing the concentration of waste in the environment to reduce mortality and/or taking advantage of this waste as food for other species.

2.1.5. The food industry and energy

The food industry uses raw material from agriculture, livestock, fishing or aquaculture. Water is frequently used as an ingredient and in the heating, cooling and cleaning of facilities. In fact, more water may be employed in food industry processes than raw materials or ingredients. Other elements that provide support are air (pneumatic automation) and certain gases (mainly nitrogen, oxygen and CO_2). The food industry is also a major producer of wastewater.

Food manufacturing processes can be broken down into operations of a physical, physicochemical or biochemical nature that are applied to raw materials with the support of elements such as water and energy. The food industry is one of the industrial sectors that consumes most energy. This is due to the high volume of product that is processed, rather than the intensity of energy consumption (various sources estimate that the energy costs are between 3 and 5% of the total).

In Spain, the food industry is the industrial sector with the highest added value (15.3%) and the second highest total final consumption (17.2%), after the metal industry. In Catalonia, the food industry is highly diverse and is also the leading industrial subsector in added value (11.3%) and the second, after the chemical industry, in total final consumption (16.8%), of which electricity accounts for 35.8%. Most of the consumption in the agri-food industry is between 0.1 and 1 kWh per kg of product.

Most of the energy that is consumed in the food industry is for heat treatment of food (blanching, pasteurisation, sterilisation; approximately 29%), cold treatment (refrigeration and freezing; estimated at 16%) and water elimination processes (evaporation and dehydration). In addition, in certain industries, a considerable amount of energy may be consumed for processes of extrusion, cooking, frying and baking; milling of cereals; and fermentation, distillation, mixing, pumping and shaking of fluids. In addition, energy consumption may be notable in processes of mechanical separation (filtration), cleaning of equipment and, as in any other industry, in services (lighting, air conditioning or heating).

Other factors that have a considerable effect on energy use in the agri-food industry are packaging, with its associated environmental impact, and the transport and storage requirements of the product until it is consumed, particularly in relation to the cold chain. The decisions of the agri-food industry must be analysed in the context of the full life cycle of products: from primary production to consumption.

The urban population is growing and has already reached over 50% of the world population. As a result, the distance between food production and consumption is generally increasing. This means that more energy is used in transport: in some developed societies in the globalised economy, food transport makes up over 10% of total transport. However, this trend may also be compensated for by an increase in the consumption of local, seasonal products.

There is still immense potential for energy saving in food production. For example, low-temperature treatments and more efficient food processing technologies provide an opportunity for energy saving if they replace high-temperature processes. An integrated analysis of the entire production process (including water use, energy consumption and waste management) should reveal synergies, as well as opportunities for saving and for the reorganisation of the relationship between production, transformation and consumption.

2.1.6 Waste management and treatment

All the subsectors of activity shown in Figure 2.1, and all the stages in the food chain produce solid or liquid (wastewater) organic waste, whose origin is the primary biomass generated by photosynthesis (energy and atmospheric CO_2) and the uptake of macro- and micronutrients from the soil.

The types of waste that are produced in the greatest quantities are:

a) Crop residue (by-products with an agricultural and energy value)

b) Slurry, manure and poultry droppings

c) Waste from the food industry (from meat, oils and fruit)

d) The organic fraction of municipal waste and domestic wastewater.

This waste causes many problems if it is not managed properly:

1) Atmospheric pollution: emissions of CH_4, N_2O, NH_3 and COV

2) Water pollution: nitrates, phosphates, organic matter, xenobiotic compounds

3) Loss of organic matter, deterioration and loss of soil fertility, erosion

4) Greater energy consumption (to replace nutrients)

5) Health problems.

Matter, like energy, is not created or destroyed: it is transformed. Therefore, surplus or unusable organic matter (waste) has an energy and agricultural value. In a circular economy, the efficiency of the entire food chain should be maximised, and nutrients, micronutrients and energy recovered from all waste. Regardless of the production system (intensive or distributed), the use of nutrients and other production factors should be made as efficient as possible to prevent pollution and loss of resources.

Thus, waste treatment is of strategic importance to the sustainability of the system. In this sector, the terminology and objectives need to be changed to move from the concept of “waste treatment”, which is defined as a method to reduce environmental impact, to the concept of “waste processing”, which is a method to obtain a usable final product with an economic value via the appropriate technological strategy. This is a new production sector whose aim is to produce energy, recover macro- and micronutrients, and reduce dependency on fossil fuels and raw materials.

The *transition to a new energy model* with a paradigm shift in production could lead to the emergence of many paradoxes, such as investment in facilities designed to obtain the maximum recovery of waste resources, whilst at the same time investing in campaigns to reduce waste production. Therefore, in addition to scientific and technological research to enable a paradigm shift in the consideration of the use of waste and wastewater as resources, training is needed to manage uncertainty and progress in a coordinated way.

In Europe, 1,400 Tg (millions of tonnes) of manure is produced a year, of which 7.8% is processed (Foged-2012b]. The main driver behind the adoption of treatment systems is pressure on livestock farmers to avoid nitrate contamination of water. Today, biological nitrogen removal systems are being replaced by nutrient recovery systems, to cut the use of mineral fertilisers or for exportation over large distances.

One key technology in these recovery processes is anaerobic digestion. This process reduces bad smells, transforms organic matter into CH_4, mineralises it, and makes it more suitable for various physicochemical processes for nitrogen or phosphorus recovery. The concept is also applicable to wastewater treatment plants, where instead of transforming organic matter into CO_2 via aerobic biological processes involving O_2 transfer and the resulting energy consumption, organic matter can also be transformed into CH_4 and nutrients recovered. This is a new paradigm in which treatment plants that consume energy become factories producing energy, nutrients and other value-added products.

The differences in composition and CH_4 production potential of organic waste justifies the need for codigestion, that is, combined anaerobic digestion of substrates from different origins. The objectives of codigestion are to achieve complementarity in composition and thus make processes more effective, standardise management methods, dampen the impact of seasonal variations in composition and production, and reduce investment and exploitation costs. This concept, which has been implemented in Denmark since the mid-1980s, responds to a need for co-treatment and co-management of waste from different production sectors in the agri-food chain, and creates synergies for mutual assistance to close the complete circle.

The organic waste management and treatment sector is key to promoting the circular economy by indirectly recovering solar energy harvested in the form of organic compounds, recycling nutrients, maintaining and improving soil quality. Therefore, it is a sector that requires considerable research and information, to which the Universitat Politècnica de Catalunya must contribute.

2.2 Responsibilities and opportunities of the UPC

The Universitat Politècnica de Catalunya (UPC), as a leading technical university in a developed European country, has a responsibility and opportunities to get actively involved and promote the changes required to shift from fossil fuels to renewable energies in all areas of activity.

Agricultural studies have a long tradition in Barcelona. In 1911, Barcelona Provincial Council founded the Barcelona School of Agricultural Engineering with two objectives: to train good farmers with solid scientific and practical foundations, and to become a research centre. After various changes in circumstances, in 1976 the school became attached to the UPC, and from 2005 the activities were moved to the Baix Llobregat Campus in Castelldefels.

The second chapter of the UPC's background document on the *transition to a new energy model* addresses *food and energy*: a basic requirement to enable any other human activity. Today, the activities that support human nutrition (agriculture, livestock farming, fishing, aquaculture, the food industry, distribution and consumption, as well as the management and, indirectly, the treatment of waste) are strongly dependent on fossil fuels and consequently will be affected by the fossil fuel crisis.

For the sustainable, harmonious development of society, the food system must also be sustainable and harmonious. One of the main challenges is to implement key enabling technologies (KET) in production processes, to facilitate innovation and the creation of new products and processes, and to develop a sustainable industrial and technological basis for the agri-food sector.

Today, the food industry needs the contribution of knowledge, techniques, teams and specialists from other areas such as electronics, information and communication technologies, photonics, nanotechnology or robotics. The success of the sector's transformation depends, to a great extent, on the rate at which this new knowledge is implemented in the sector.

Consequently, the UPC considers that it must promote and boost the following actions:

2.2.1 Studies and analysis of food

Food is one of the most basic human needs. In a world that is increasingly urban, most of the food resources must come from outside cities and the distances are increasing.

The food supply in western Europe has been based on two main models. In the first, which was in use from the Late Middle Ages until the eighteenth century, the food supply of towns and cities was in the hands of local governors who regulated the food trade and combined protection with fair prices. In the second, which took shape in the nineteenth century with the introduction of economic liberalism and the construction of states, the free market was established and local authority's power to intervene was diminished [Renom-2016].

Today, with globalisation and the low prices of fossil fuels until recently, some of the main foods have become *commodities* (wheat, rice, sugar and soya), and even perishable products with low added value (common fruit and vegetables) are marketed between continents. Cities grow regardless of the agricultural production capacity of surrounding land, and the costs of transport, storage and waste transformation are rising.

Food balance sheets are some of the most valuable information compiled by the FAO. For a specific country, they correlate the production and supply of the main plant and animal products; analyse the use of each product in human food, animal feed and other uses; and identify the contribution of each food (plant and animal) to human energy (calories), protein and fat intake.

From the perspective of production, Catalonia has specialised in certain food sectors (vineyards and wine, fresh fruit, the pig industry and the food industry in general). However, as it is not a state (FAO) and because there are no other administrative organisations that compile food balances, none are available on this population.

Food balance data are vital to:

- Draw up food supply policies, which are particularly important for a population like that of Catalonia in which primary food production is generally insufficient, and in a phase of energy transition that will have a profound effect on current balances.
- Correlate the health of the population with food habits. Fat intake in the Spanish population (of which Catalonia forms a part) rose from 68 grams per day in 1961 to 160 grams per day in 2011: an increase of 137% (worldwide, this increase was 75%).

2.2.2 Agri-food sector, resources and energy

Agriculture

Agriculture is an activity that consumes a high amount of resources. The new approaches to optimising energy use must act at the levels of the living organisms that we farm, the environment in which they develop, and the interaction between these two factors.

Living organisms. The genetically improved varieties that are mainly used in Catalonia (almost 100% of vegetables and cereals) were obtained considering an environment with a high energy investment. We must start to revise this paradigm, and use all our capacity for engineering living systems to create plants that use energy more efficiently and do not require such a high level of external intervention as the varieties we use today. The most extreme case is that of plants protected in greenhouses where we can subject them to very different conditions from those outside, in exchange for investing a lot of energy in the system.

Agricultural land. Agriculture is by far the human activity that uses the largest surface area. World averages of agricultural area per capita (0.22 hectares per inhabitant in 2011) are already very low compared to pre-industrial periods, due to inputs that consume fossil fuels (fertilisers, pesticides, irrigation and intense mechanisation). Taking this average, the area needed to feed the population of Catalonia (7.5 million inhabitants) is around 1,650,000 ha; just above 50% of the territory (3,210,000 ha). Currently, Catalan agricultural land that is in use occupies only 780,000 ha (almost 25% of the territory).

Water. Despite the large population and the size of the industrial sector in Catalonia, agriculture absorbs 69.6% of the water (93.7% in the Ebro basin).

Fertilisers and pesticides. Despite the current trend of moderation, the rise in use of these inputs has been dramatic in recent decades. In addition to putting an economic burden on farmers and creating dependency, these products pollute soil and underground water and have a direct effect on energy consumption for their production. However, on paper, EC countries are committed to reducing pesticide use (Directive 2009/128 EC on the sustainable use of pesticides).

Livestock, fishing and aquaculture

Catalonia is a major producer of animal products (28% of the total). In addition, the associated industry, particularly that of products made from pork derivatives, is sizeable.

The model of intensive livestock farming is supported by the importation of resources and cheap energy that favours the intercontinental transport of raw materials and creates an imbalance in the distribution of nutrients. However, it is also an industry that provides added value. To resolve this contradiction, studies are required on how the sector should evolve in the framework of the energy transition.

Livestock farming requires considerable consumption of fodder, feeds and other resources, many of which are highly dependent on fossil fuels. It produces a large amount of waste (solid, liquid and gas) that has a profound impact on the environment, as it contaminates soil and underground water, and on climate change.

Although fishing and aquaculture are smaller sectors, they are still active as they provide other kinds of fats. Therefore, the UPC should take them into account with respect to training and technological research to optimize consumption and production.

Food industry

The food industry transforms primary plant and animal products into processed food products. In Catalonia, it is the industrial sector with the highest economic value (21%).

Although the energy costs are low in relation to the overall costs of the sector (<3%), it is one of the sectors that uses most energy. According to the Statistics on Energy

Consumption in the Industrial Sector (ECESI) survey (ICAEN, Government of Catalonia), the food industry uses 16.8% of the energy of the entire industrial sector, of which 35.8% is in the form of electricity and the remaining 64.2% in various forms of thermal energy.

Most thermal processes in the food industry use low and medium temperatures. Therefore, they can easily be supplied by solar thermal technologies using flat-plate collectors (low temperature), solar thermal collectors (medium temperature) and various heat pump technologies (low and medium temperatures).

In general, there is considerable room for energy improvement in the shift from fossil resources (fuels) to new renewable energy resources (normally in the form of electricity). Water is a scarce, fragile resource in Catalonia, and there is likely to be much less water, a less regular supply and more demand in the future. As the agri-food trade balance indicates a clear shortfall, we should also consider the high dependence on this resource in the form of virtual water.

A review of food industry processes could also lead to substantial savings in primary plant and animal resources compared to the production that is currently obtained (a reduction in wastage or using waste: circular economy).

2.2.3 Opportunities to use waste

All organic waste, organic compounds and nutrients in wastewater from all sectors of activity in the agri-food system, including agriculture, fishing, and domestic or other consumption, has its origin in solar energy harnessed through photosynthesis, atmospheric CO_2, water and nutrients, which must be returned to the soil. Therefore, organic waste contains energy and non-renewable nutrients.

It is a resource. Consequently, the economic sector that manages and processes organic waste must be conceived as a production industry that turns waste into new products with market value. This requires a paradigm shift in the concept of waste or wastewater. Waste is no longer something to be eliminated or treated to reduce its environmental impact, but something that must be transformed to improve the global energy balance and reduce the importation of raw materials such as nitrogen and phosphorus. This is a new approach that is being adopted in western countries, and needs new engineers who have solid scientific and technical foundations, a global view of the problem, and an integral view of the solutions.

In the context of a circular economy, each subsector of activity could recycle or transform its own waste. However, the specific characteristics of each subsector mean that this objective cannot always be achieved. Complementarity and synergies obtained from co-management and co-treatment could make facilities more efficient, particularly considering that the shared objective is to close the nutrient cycle and recover the energy content of organic compounds. This new paradigm requires collaboration between sectors, for which new work schemes and mid- and long-term planning are needed.

Universities have an important role to play in this paradigm shift, by promoting research and the development of new technical and organisational solutions, and training technicians who have a comprehensive, integrating vision and the capacity to manage uncertainty in an environment of changing demands.

2.3 Future areas of work of the UPC

A series of future areas of work is proposed that the UPC wishes to, can and must adopt to respond to the challenge of the *transition to a new energy model* in the area of Food and Energy.

A. Through **cross-cutting activities** (advance research, test new solutions, participate actively in the general debate and train future generations), the University will work on key aspects such as:

- Soil, water and air quality
- Fertilisers and pesticides
- Precision agricultural techniques
- Renewable energy carriers
- Local agricultural systems
- Impact of intensive livestock farming
- Air conditioning and lighting systems for livestock barns
- Energy efficiency in fishing
- Responsible and sustainable fishing and aquaculture
- Circular economy of production processes
- Surplus organic matter.

B. The University will undertake the following **specific actions** in this area:

I. Promote the incorporation of key enabling technologies (KETs) of industry 4.0 into the agri-food sector, both in primary production and the processing industry, and in distribution and HORECA (hotel, restaurant and catering).
II. Contribute as much as possible to incorporate biosystems technology and boost engineering of living systems (biotechnology and genetic enhancement) to obtain plants that are more efficient at gathering and transforming energy (including processes of uptake and transformation of nutrients).
III. Work in the area of food balances. Promote research at the UPC into food from the perspective of a basic service according to new, integrating concepts governed by the energy transition. Provide services for compiling food balances for Catalonia.
IV. Work in the area of wastage. Study all aspects of the process of food wastage (production systems, preservation systems, packaging, etc.) to reduce the high percentages of food that are produced and not consumed.

3. Habitability and energy

Contents

3.1 Analysis of the situation and tendencies

3.1.1 The concept of habitability

Habitability is an asset that meets the basic need of shelter for human activities, and provides socially appropriate conditions for carrying them out. These conditions include factors relating to dimensions, the environment (thermal, light and acoustic comfort, as well as air quality), safety (in general use and in the face of fires, earthquakes, floods and other natural catastrophes), and the layout of spaces for carrying out these activities with the required level of privacy.

The first place where habitability is observed is in homes, which provide shelter to meet the most basic needs (including sleeping and resting, preserving and preparing food, personal hygiene and waste disposal, storing personal possessions safely, and maintaining relationships with members of the household and others).

However, a socially acceptable life today also requires access to a series of services (education, culture and healthcare, among others) and workplaces (offices, workshops and factories). These form part of habitability at a larger scale than the dwelling: an urban scale that brings together and orders the facilities in a structure that also reflects society's relationship with the environment through infrastructure for mobility (of people, materials, water and energy) to organize and define the urban space. This relationship is a kind of social metabolism that is clearly expressed in the form of the territory and the social perception of this form: the landscape.

Thus, buildings for dwellings, services and work, as well as the urban space are the components that determine habitability, supported by infrastructure that connects the landscape.

3.1.2 Habitability and energy

Like any activity that modifies the environment, habitability is associated with the use of energy, and with the accelerated degradation of energy available in the environment. Essentially, there are two phases in which habitability degrades energy: construction and maintenance.

The shelter provided by habitability is based on the construction of buildings and spaces, organised to establish conditions relating to dimensions, safety and the environment. The construction process requires material that must be produced through processes that use energy.

Today, the construction of a habitable square metre requires between two and three tonnes of materials, and the energy needed to manufacture these materials is between

4,000 and 6,000 MJ, which is approximately the energy produced by the combustion of between 100 and 150 litres of benzine. Therefore, a dwelling of 100 m^2 requires energy to manufacture its materials equivalent to that consumed by a standard car on a journey of between 150,000 and 225,000 km.

In addition, we must consider the greenhouse gas emissions due to manufacturing the materials used in this dwelling of 100 m^2 usable area. If we include the emissions (and energy) of the materials required to construct the non-habitable m^2, such as the garage and shared areas, the figure would be above 50 tonnes of CO_2. In 2007, just before the recession and during the construction boom, the manufacture of construction materials for buildings in Spain accounted for almost 10% of greenhouse gas emissions (GHG). In addition, the construction of infrastructure requires energy to carry flows that enable habitability, and those required to build the public space. This is a lower figure, but significant at macroeconomic scale.

The maintenance of habitability within built spaces also requires energy: partly to attain the required environmental conditions with heating, air conditioning and lighting; and partly to support human activities within buildings by supplying power to the equipment that is used (including cookers, electrical household appliances and communication devices). In our homes, the distribution between the energy required to achieve habitability and that consumed by activities is in a proportion of approximately 60% to 40%. The total energy used in homes in Catalonia is around 45,000 MJ per year for an average dwelling, which is equivalent to over 1,000 litres of benzine per year, or a car that travels 18,000 km per year.

These figures should also be examined in a macroeconomic context: a third of final energy consumption in Catalonia is used in buildings (excluding industrial buildings). Maintenance of habitability and activities within buildings accounts for a third of the social use of energy. Our model of habitability is strongly dependent on energy, and consumes much of the energy used socially.

The energy balances of the International Energy Agency [IEA-2017] establish the intensity of final energy consumption by geographic area (the world, OECD countries, non-OECD countries, EU28, Spain and Catalonia). The energy uses of Spain and Catalonia are close to the average for the EU28. The energy use for dwellings accounts for a surprisingly low proportion of final energy consumption (16.6% in Spain and 13.1% in Catalonia, compared to an average of 24.3% for the EU28). In contrast, energy use for transport is surprisingly high (48.4% and 49.9% of final energy consumption in Spain and Catalonia, and 36.3% in Europe). The low energy use in dwellings is due to the more temperate climate and less need for heating (most of Catalonia has a temperate Mediterranean climate, and household energy consumption that is slightly lower than all of Spain). The second aspect indicates an excessive use of transport, particularly private vehicles.

The SECH-SPAHOUSEC project undertaken by the Institute for Diversification and Saving of Energy (IDAE, Government of Spain), [IDAE-2011] enables an analysis of the distribution of energy spending in homes, as shown in Table 3.1.

Air conditioning, excluding heating, absorbs 50% of energy uses. Progressive growth in domestic air conditioning has led to an increase in energy consumption, although figures dropped during the recession. The second largest energy cost in the home is domestic hot water, at almost a fifth of the total. Energy consumption for domestic hot water is also increasing when economic conditions permit, but a high proportion of around 50% should be met by solar energy. The amount of energy consumed by lighting has dropped, due to greater efficiency of lightbulbs. Despite gradual improvements in efficiency, energy use by domestic electrical appliances has increased, due to an increase in type and number of appliances.

Figure 3.1 Energy uses in Spanish homes (kWh/(dwelling per year))

Concepts	Overall				Apartments		Single family	
	Total	Fuels	Electr.	%	Total	Fuels	Total	Fuels
TOTAL	**9.924**	**6.419**	**3.487**	100,0 %	**7.545**	**4.189**	**15.516**	**11.714**
Heating and cooling	4.744	4.395	338	47,8 %	2.506	2.167	10.023	9.685
Domestic hot water	1.877	1.611	260	18,9 %	1.958	1.722	1.664	1.345
Lighting	410		410	4,1 %	397		440	
Food	1.705	413	1.292	17,2 %	1.520	299	2.146	684
Cookers, ovens	*915*	*413*	*502*		*793*	*299*	*1.206*	*684*
Fridges, freezers	*790*		*790*		*727*		*940*	
Cleaning	458		458	4,6 %	435		512	
Washers, dryers	*328*		*327*		*315*		*356*	
Dishwashers	*131*		*131*		*120*		*156*	
Appliances	730		729	7,4 %	729		730	
Stand-by	*231*		*231*		*237*		*216*	
TV	*263*		*263*		*249*		*295*	
Computers, others	*236*		*236*		*243*		*220*	

Source: SECH-SPAHOUSEC project [IDAE-2011]

3.1.3 The evolution of habitability and energy

The situation has not always been like this. The socially acceptable conditions that define habitability have adapted to the opportunities presented by access to energy, and generated models that became more dependent on energy as access to it was secured.

Today, some situations that were customary not many decades ago are classified as energy poverty and considered an unacceptable social problem. For example, the increase in household income from the 1970s to the start of the recession of 2008 enabled the systematic adoption of heating systems in dwellings (at the start of 1980, heating was still considered a luxury in social housing). Today, over 50% of homes have air conditioning devices in some rooms.

However, the increasingly accessible energy (from the end of the 1970s to the start of the new century, decreasing energy costs coincided with a rise in household income) also meant that efficient energy use was not very important in the construction of buildings. Consequently, much of the building stock in Catalonia (32%, built between 1980 and 2007) was neither designed nor constructed taking the demand of energy efficiency into account.

Furthermore, energy efficiency was overlooked in many of the buildings constructed in the 1950s, 1960s and the start of the 1970s, many of which were put up urgently to provide urban dwellings for a population that had migrated from the countryside with precarious economic conditions, a problem that was resolved with neighbourhoods that were also precarious in terms of the available services and the quality of dwellings. These neighbourhoods now make up the suburbs of our cities.

City centres have declined as models of the city, in the face of new demands. Among other things, they have lost the traditionally accepted conditions of comfort, which were never explicitly stated, lost the strategies to achieve these conditions, and lost the elements of infrastructure that provided city centres with the resources needed to produce and maintain habitability. In fact, the constant increase in production associated with the industrial revolution and known as progress, which fuels a constant rise in consumption, has led to offerings of habitability in traditional city centres becoming inadequate. Households that could keep up with economic progress have abandoned these areas for new offerings in neighbourhoods that can support a contemporary social metabolism.

Thus, our existing cities and building stock require high energy consumption to provide the habitability demanded by society.

3.1.4 The energy crisis and habitability

The energy crisis in both resources and waste forces society to make an inevitable shift in energy source to renewable energies. The change is urgent, and buildings will have a key role to play.

We could continue with “business as usual”; with the expected progress of current policies to improve energy efficiency. However, in this case, to meet the demand for habitability associated with population growth (and hopefully a corresponding increase in income) from 7.2 billion inhabitants to 9.6 billion in 2050, buildings will emit greenhouse gases in 2050 in amounts up to the limit that caps the temperature rise at two degrees. In other words, habitability will account for all the permitted emissions, making it impossible to meet the first climate change target.

A change in energy model will require decentralisation of production and a predominance of electrical energy. Both conditions are associated with the use of renewable energies, and strongly related with the built environment (buildings and urban spaces) in terms of its geographic dispersion, the types of energy sources that are used, and the amount of energy consumed. In 2010, for example, 23% of primary energy was allocated to the final energy consumption of buildings; a percentage that it will be hard to reduce in the future. Directly or indirectly, buildings already generated over 18% of GHG emissions in 2010.

The need for a rapid change in model is leading to new, radical, urgent demands that affect both buildings and cities.

In Europe, the Energy Efficiency Directive 2010 [UE-2010] established the nearly zero-energy building (nZEB) standard for a building with high energy efficiency and very low energy consumption, supplied by renewable energy sources. Compliance with this standard will be compulsory for all new buildings from 2020. The Energy Efficiency Directive 2012 [UE-2012] requires a viable strategy for transforming existing building stock into energy efficient buildings, using nZEB as a reference point.

Equally, new forms of harvesting, transforming and distributing energy are being developed in which the urban scale (at neighbourhood level) is of central importance, and in which energy consumption for urban services and for the mobility of passengers and goods should be considered. In these new forms, onsite renewable energy sources, located in buildings and neighbourhoods, are key to a model in which production and consumption must have a very different structure to the current one. Notably, studies undertaken by the Collective for a New Social and Sustainable Energy Model (CMES; Ramon Sans [Sans-2014] and Eduard Furró [Furró-2016]) indicate that in Catalonia the area required to support a 100% renewable energy model could be between 40,000 hectares (according to the first author) and 66,000 hectares (according to the second author), when the developed area in Catalonia is around 215,000 hectares [Idescat-2017].

Climate change mitigation strategies also create demands on buildings and cities. EU interest in green infrastructure as an instrument to protect and enhance biodiversity has taken a new direction with the need to include urban and production areas, and the possibility of using green infrastructure as elements that provide urban services, thus forming a new relationship between cities and the territory. In our current social metabolism, the territory supplies resources to the city and absorbs the waste, but does so by consuming natural capital and degrading the processes that govern its biophysical matrix (slope, soil, substrate, flora, fauna and climate), which progressively reduces the territory's capacity for renewal and its ability to produce socially useful goods and services.

3.1.5 The need for a new concept of habitability

To the global challenge of the transition to the new energy model, we must add specific challenges relating to habitability in Catalonia. A demographic transition began in Catalonia at the end of the 1970s, when the base of the population pyramid narrowed, indicating the end of a long process of population growth. The stabilisation of the population has only been altered by the onset of immigration to Catalonia. This demographic transition has changed social demands for habitability.

This is firstly because demographic growth drove a construction sector that was basically dedicated to putting up buildings to provide shelter for the population, within a city that was also continuously expanding. In Catalonia, stabilisation of the population has meant that expansion in building stock is no longer a functional need (there are already fewer than three people per dwelling on average), and the past rates of new construction activities are no longer necessary.

Secondly, a change in population model means that households have very different characteristics to those that defined habitability requirements up to now. Population ageing due to better living conditions has changed the needs of dwellings' inhabitants, particularly with respect to physical accessibility (in other sections of the background document we discuss virtual accessibility) and safe use. Models of household now vary widely, and many are far from the family home with children that shaped our dwellings. Many households require new relations between their members and the opportunity for these relations to have a place and suitable expression in the home. Furthermore, urban life has evolved, as have domestic and social activities, and there are new demands and requirements supported by new equipment, with new opportunities for communication and information management.

Thirdly, the transition to a new energy model forms part of a necessary paradigm shift in our relationship with the environment; a change that must transform the metabolism of our society, with new forms of production and consumption that are not based on the systematic destruction of natural capital. This implies a change in our relationship with the territory, with infrastructure systems that put the landscape (the uses, planning and social perception of the territory) at the centre of social debate, as it is the synthesis of the processes that shape it.

For this reason, we need a new concept of habitability that can meet the challenge of the energy transition and the social challenges that our society must address. This new habitability must be based on recognition of the existing building stock and the existing city as its support. The city plays an essential role as the scale on which intervention will be undertaken, and a new landscape will be created as a result of its new infrastructure.

3.1.6 Challenges of the new concept of habitability

How can we meet the new habitability demands in existing buildings? How can we functionally adapt the existing building stock? How can we interpret it? How can we renovate it to embrace the new homes and adapt it to the needs of the population? What strategies do we need to use? How can we reconsider the demands for safety, services and comfort in the new concept of habitability? How can we attain nZEB? How can we interpret the existing support to achieve nZEB? How can we re-habilitate the existing housing stock? Which concepts do we need to use? And which technologies?

Which materials should we use in this new concept of habitability? What are the characteristics of the materials required to reduce the energy intensity of habitability and create a new landscape for a new relationship with the territory that supplies them? How can we understand and treat the materials that form part of the built city; the existing buildings on which to project this new habitability?

And in which city? What are the keys for regenerating the city, for interpreting a sustainable model of life with a new energy model built on urban models based on other social metabolisms, with other relationships with the environment, expressed in the infrastructure that supports the cities and in the urban form that they have generated? What strategies and instruments of regenerative urban development should be used?

How can we create infrastructure for the new concept of habitability to reconnect us with the territory? What opportunities are provided by combining the infrastructure of biodiversity with the demands for a new sustainable urban model and a new social metabolism? Which instruments do we need to create a new landscape (*in situ* and *in visu*)?

3.2 Responsibilities and opportunities of the UPC

We consider that the answer to these questions should be associated with the University's role. UPC statutes state that the University must support the progress of Catalan society in the University's areas of expertise. The challenge of the transition to the new energy model is profound, transformative and has a considerable impact on engineering and building, which are areas covered by the UPC. Therefore, our University's participation and leadership in this transition is vital. The UPC must provide support through its activities, so that it becomes a tool for social, economic and cultural progress.

The answers to the above questions should be developed in the three areas in which our university has responsibilities: training, research and technology transfer:

3.2.1 Habitability as a cornerstone

The UPC must participate actively to further knowledge of situations and trends relating to habitability, to create new visions and transmit them in students' education as core learning areas. It must also promote research and universities' active role in social debate.

3.2.2 Efficiency in the production and maintenance of habitability

A field of study that is easily recognisable is the generation of a new vision, knowledge, good practices and technologies relating to saving resources in the creation and maintenance of habitability. The first, unavoidable objective of this field is to meet the challenge of nZEB.

3.2.3 The new relationship between the city and the environment

The services that a city needs must be produced through processes that do not reduce the territory's production capacity. To achieve this, harmony must be fostered between the city and the processes, through methods such as recovering knowledge integrated in the urban form of traditional cities, and the new "green infrastructure" promoted by the EU.

3.3 Future areas of work of the UPC

A series of future areas of work is proposed that the UPC wishes to, can and must adopt to respond to the challenge of the *transition to a new energy model* in the area of Habitability and Energy.

A. Through **cross-cutting activities** (advance research, test new solutions, participate actively in the general debate and train future generations), the University will work on key aspects such as:

- Demand for habitability vs. needs/behaviours
- The impact, flows and transformation of the urban, material and social metabolism and the resources involved
- Territorial planning in the biophysical matrix
- Intervention, renovation and construction technologies
- Passive energy efficiency
- Systems for heating domestic hot water
- New "prosumer" (producer and consumer) model
- Processes of civil participation and involvement
- Interventions for the built city

B. The University will undertake the following **specific actions** in this area:

I. Promote a vision of habitability as a need to be met in architecture, building and the city, and address the impact of habitability on territory and landscape. This vision must enable us to interpret both current trends and models inherited from the past.

II. Work to achieve efficiency and suitable uses of energy and other resources in relation to the utilisation of buildings and developed areas (with respect to air conditioning and heating, lighting, demands of activities, communication and safety systems, maintenance, etc.). Work to meet the challenge of nZEB: buildings that consume almost no energy.

III. Develop new infrastructure models for services (water, energy and mobility) that are compatible with the transition to a new energy model. These should include green infrastructure for connection with the territory, and provide the fabric required for the transformation of the existing city.

4. Accessibility, mobility and energy

Contents

4.1 Analysis of the situation and trends

4.1.1 The value of physical and virtual accessibility

After food and habitability, the most important value that advanced societies provide for personal development is physical and virtual accessibility to places, goods, services, information and knowledge. This is an essential prerequisite for social participation and inclusion.

During a long period of history, the only form of accessibility available to humans was physical, that is, accessibility through the movement of people and things. However, virtual accessibility has become increasingly relevant, starting with the development over a century ago of the telegraph and the telephone, followed by that of the radio and television, and, in recent decades, the new information and communication technologies (ICT technologies) associated with the internet and the mobile phone.

A combined analysis of physical and virtual accessibility is of interest today for two reasons. First, the paradigm shift in energy has a considerable impact on the bases of physical accessibility (mobility and transport) and an increasing impact on virtual accessibility (telecommunications, internet and mobile phones). Second, virtual accessibility (in terms of information and communication and the capacity to operate at a distance) has become closely intertwined with physical accessibility, and may at times work with it, compete against it or replace it.

Mobility is the activity of moving people and goods from one place to another that relies on technical means of transport (energy carriers, vehicles, infrastructure, forms of organisation and management). Physical accessibility (which is a value) should not be confused with mobility (which is the activity) and transport (which is the means). Better accessibility can be obtained with more limited, but more suitable, mobility and means. A similar argument can be made in relation to virtual accessibility (which is the value), information flows (which are the activity) and communication systems (which are the means).

In short, the paradigm shift in energy encourages us to reflect positively on the values of accessibility in general, through improvements in ways of combining physical and virtual accessibility and developing the means to achieve this. Solutions must be found for systems and transport in particular that have been based on finite, polluting energy sources (oil derivatives) that should be progressively abandoned in favour of renewable, clean energies.

4.1.2 Accessibility and human settlements

Population growth and the rising complexity of our societies have increased the requirements of accessibility at the right time and place. Mobility is the activity that makes it possible for people and goods to move by means of transport for activities that require physical presence. Information flows enable remote interaction through information and communication technologies for activities that do not require physical presence.

Mobility in urban and metropolitan areas, in which private cars (particularly in developed countries) and light commercial vehicles are widely used, accounts for a substantial proportion of society’s energy consumption and greenhouse gas emissions, and has a local impact on health. Long distance mobility also has a significant impact on energy uses and the environment. Planes play a key role in transporting passengers over long distances, and high-speed trains are gaining ground for middle distances. Shipping is the main means of transporting goods, followed at a distance by rail transport and heavy vehicle road transport.

Mobility should be considered from a holistic, sustainable perspective that covers technological and non-technological elements and their interactions, and in which cities have dynamics that must be studied specifically. Mobility has become so complex and absorbs such a sizeable proportion of our resources that we must go beyond a mere change in technologies: beyond a simple shift in vehicle engines from combustion to electric. We must also review the concept of mobility based on personal vehicles. Technology is a necessary condition today, but it is not sufficient, and new approaches must be sought.

A search for the sufficient conditions leads us to study the interactions between urban settlements, human activities, land uses and physical and virtual accessibility, as well as the interactions between these factors and energy. An understanding of these complex interactions requires integrated models to assess policies focused on the objectives of sustainability. In other words, a key characteristic of the quality of a society will be the degree of accessibility of its cities and other settlements in the territory, in the framework of sustainability.

4.1.3 Mobility, transport and energy

The availability of cheap, abundant energy in recent decades derived from fossil fuels, particularly crude oil, has enabled the globalisation of the economy, encouraged people to make increasingly frequent and longer journeys, and fostered growing dependence on products and services consumed far from where they were produced. Many production processes have been broken down and distributed around the world so that considerable movement of goods is required for products to be completed, which has made transport key.

However, at global scale, the first limits to the use of crude oil and its derivatives are beginning to be perceived, which forces us to reconsider mobility in general and a transition to renewable energy sources. If we only account for energy carriers that propel vehicles, 30.6% of world final energy consumption in 2014 was dedicated to transport (39.9% in OECD countries and 24.3% in non-OECD countries). If we also consider the energy required to manufacture and maintain vehicles and infrastructure, this percentage could increase by over 10 points.

Table 4.1 shows for 2014 the total final consumption per capita (excluding non-energy uses) and the consumption of energy per capita for transport in the world, OECD countries, non-OECD countries, the EU28, Spain and Catalonia. Catalonia has one of the highest levels of total final consumption in its surrounding environment (23,140 kWh per inhabitant per year) and even higher levels of consumption for transport than neighbouring countries (11,540 kWh per inhabitant per year), at almost half of its total energy consumption and more than Spain and Europe.

Table 4.1 Amount of energy used for transport (per capita values)

Source: [IEA-2016]		World	OECD	Non-OECD	EU28	Spain	Catalonia
Total Final Consumption (TFC)	kWh/(inhab·year)	13.760	31.530	9.990	24.910	21.360	23.140
Transport Energy (TE)	kWh/(inhab·year)	4.205	12.590	2.425	9.045	9.815	11.540
Ratio TE/TFC	%	30,6 %	39,9 %	24,3 %	36,3 %	46,0 %	49,9 %

4.1.4 Transport modes for passengers and goods

Table 4.2 summarises passenger and goods transport in the world, and its relationship with energy uses and greenhouse gas emissions for 2014. In addition, a figure is given as a reference for 2000. The data are mainly drawn from estimations based on the Mobility Model (MoMo), promoted by the International Energy Agency (IEA) ([Park-2015], [Cazzola-2016], [Teter-2016]).

Table 4.2 Activity, energy and emissions in passenger and goods transport

Passengers	2000	2014							
	Activity	Activity				Energy		Emissions	
	World Gpkm	World Gpkm	World %	OECD Gpkm	Non-OECD Gpkm	World TWh	World MJ/pkm	World $TgCO_2$	World gCO_2/pkm
Total	29.500	48.600	100,0 %	19.500	29.100	19.170	1,40	4.820	100
Cars	13.500	24.300	50,0 %	72,5 %	35,0 %	65,2 %	1,85	64,5 %	130
Bus	9.500	13.200	27,2 %	9,5 %	39,0 %	10,9 %	0,60	11,5 %	45
Plane	3.000	4.600	9,5 %	14,5 %	6,0 %	15,9 %	2,40	16,3 %	170
2-3 wheels	1.500	3.300	6,8 %	0,5 %	11,0 %	6,5 %	1,35	6,5 %	95
Rail	2.000	3.200	6,6 %	3,0 %	9,0 %	1,4 %	0,30	1,2 %	20
Minhab	6.128	7.244		1.264	5.980				
pkm/inhab	4.810	6.710		15.430	4.870				
kWh/inhab		2.650		7.540	1.610				
$kgCO_2$/inhab		670		1.900	410				

Goods	2000	2014							
	Activity	Activity				Energy		Emissions	
	World Gtkm	World Gtkm	World %	OECD Gtkm	Non-OECD Gtkm	World TWh	World MJ/tkm	World $TgCO_2$	World gCO_2/tkm
Total	70.100	110.700	100,0 %	45.000	65.700	11.390	0,36	3.000	27
Shipping	51.000	84.300	76,2 %	75,2 %	76,8 %	30,1 %	0,14	30,7 %	11
Lorry	5.500	10.700	9,7 %	13,8 %	6,8 %	56,5 %	2,08	55,0 %	154
Rail	10.500	10.100	9,1 %	8,0 %	9,9 %	5,0 %	0,35	7,7 %	23
Others[1]	3.100	5.600	5,1 %	3,0 %	6,5 %	8,4 %	0,59	6,7 %	35
Minhab	6.128	7.245		1.265	5.980				
pkm/inhab	11.440	15.280		35.570	10.990				
kWh/inhab		1.570		4.340	990				
kgCO2/inhab		410		1.140	260				

[1] *This includes transport in oil pipelinesand gas pipelines. Sources: [Park-2015], [Cazzona-2016], [Teter-2016]*

From 2000 to 2014, passenger transport increased 64.7% (from 29,500 to 48,600 Gpkm; billions of passengers per kilometre), goods transport increased 57.9% (from 70,100 to 110,700 Gtkm; billion tonnes per kilometre), and the world population increased 18.2% (a considerable increase in 14 years). Therefore, despite the 2008 recession, global transport is in a phase of rapid expansion.

In 2014, each person in the world travelled 18.4 pkm by motorised means and the economic system moved 41.9 tkm of goods. In OECD countries, these figures rose to 42.3 pkm and 97.5 tkm, while in non-OECD countries they stood at 13.3 pkm and 30.1 tkm. Not all transport modes are equally efficient or have the same modal distribution in OECD and non-OECD countries.

In terms of passenger mobility, citizens of OECD countries mainly use the car and the plane (together, these modes account for 87.0% of journeys in pkm). These modes consume the most energy (1.85 and 2.40 MJ/pkm, respectively), and therefore account for 96.1% of transport energy costs and 95.9% of transport emissions. Other modes (bus, motorbike and rail) account for 13.0% of the pkm, only use 3.9% of the energy and generate 4.1% of the emissions.

In non-OECD countries, cars and planes are used for less than half of all journeys (41.0% in pkm), but represent 65.5% of transport energy costs and generate 66.0% of transport emissions. The remaining modes account for 59.0% of the pkm, only use 34.5% of the energy, and generate 34.0% of the emissions. Therefore, the average transport energy consumption in OECD countries is 1.75 MJ/pkm, while in non-OECD countries it drops to 1.20 MJ/pkm. These figures are above and below the world average of 1.42 MJ/pkm.

Shipping was predominant in goods transport (76.2% of tkm, tonne-kilometres transported), with road (9.7%) and rail (9.1%) lagging far behind. The differences between OECD and non-OECD countries were not as pronounced. Shipping requires very little energy (0.14 MJ/tkm), rail transport more than double this amount (0.35 MJ/tkm) and road transport over ten times more (2.08 MJ/tkm). Therefore, lorries that that only transport 9.7% of the tkm use 56.5% of the energy consumed in transporting goods when ships, which transport 76.2% of the tkm, only use 30.1% of the energy.

Although the activity of transporting passengers (48,600 Gpkm) is lower than that of transporting goods (110,700 Gtkm), the energy used in the first (19,170 TWh) is clearly higher than that used in the second (11,290 TWh). In other words, at global scale, transporting one pkm requires energy and generates emissions (1.42 MJ/pkm, 100 gCO_{2eq}/pkm) around 4 times higher than transporting one tkm (0.36 MJ/pkm, 27 gCO_{2eq}/pkm).

Urban and on-urban transport

Table 4.3 shows the breakdown in terms of energy consumed (TWh per year) between urban and non-urban transport. A certain degree of balance can be seen (12,860 and 17,700 TWh per year).

Table 4.3 Distribution between urban and non-urban transport (TWh/year)

Source: [Teter-2016]	Total World		Urban		Non-urban	
Total	30.560	100,0 %	12.860	100,0 %	17.700	100,0 %
% (urban/non-urban)	100,0 %		42,1 %		57,9 %	
Passengers	19.170	62,7 %	10.480	81,5 %	8.690	49,1 %
Goods	11.390	37,3 %	2.380	18,5 %	9.010	50,9 %

In the urban environment, passenger transport is predominant (81.5%), while in the non-urban environment, passenger and goods transport is relatively equal (49.1% passengers and 50.9% goods).

4.1.5 Manufacture and number of motor vehicles in use

The impact of car manufacture and the increase in the number of vehicles in use, particularly in cities, leads us to consider whether we can continue with the current model of individual mobility. Table 4.4 on the evolution of manufacturing and the number of motor vehicles in use was compiled with data provided by the International Organisation of Motor Vehicle Manufacturers (OICA) [OICA-2017].

The manufacture of each new car involves high use of materials as well as embodied energy (the energy invested in materials and processes) of around 100 GJ, which is equivalent to that consumed by the vehicle to move around 50,000 km. If the vehicle travels around 200,000 km, it will consume approximately 400 GJ of fuel. Vehicles tend to travel less than one hour a day and are not used for the remaining 23 hours. Hence, they are underused resources.

Table 4.4 Evolution in manufacturing and the number of motor vehicles in use

	Year	WORLD	OECD	Non-OECD	USA	China	EU28	Spain	Catalonia
Production (Mu/year)	2000	59,1	50,6	8,5	12,8	2,1	19,0	3,03	0,62
	2016	95,0	51,3	43,7	12,2	28,1	18,4	2,88	0,55
increase	%	60,6 %	1,3 %	415 %	-4,7 %	1.260 %	-3,1 %	-4,8 %	-11,3 %
Number of MV in use (Mu)	2005	892	657	235	238	32	263	25,2	4,57
	2014	1.236	741	495	258	142	291	27,2	4,97
increase	%	38,6%	12,8%	110%	8,6%	351%	10,9%	7,8%	8,7%
MV/ 10^3inhab	2014	170	585	83	810	105	574	585	670

MV = Motor Vehicle (includes all vehicles with 4 or more wheels). Source: [OICA-2017]; Catalonia, [Idescat-2017a]

The global manufacture of motor vehicles (not including motorbikes) rose 60.6% from 2000 to 2016 and, despite a brief drop after the 2008 crisis, increased from 59.1 to 95.0 Mu/year (millions of units per year). However, while motor vehicle manufacture in OECD countries grew only 1.3% (from 50.6 to 51.2 Mu/year), in non-OECD countries it rose by 375% (from 8.5 to 43.7 Mu/year). Vehicle manufacture in China, which is now a leader, increased from 2.07 to 28.1 Mu/year between 2000 and 2016 [OICA-2017].

Between 2005 and 2014, the number of vehicles in use worldwide went up 38.6% from 892 to 1,236 Mu. However, while growth in OECD countries was 12.8% (from 657 to 741 Mu), in non-OECD countries it more than doubled (110.4%; from 235 to 495 Mu). The number of vehicles in use in China more than quadrupled (from 31.6 to 142.4 Mu), so that China now has the third most motor vehicles in use, after the EU28 (291 Mu) and the USA (258 Mu) [OICA-2017]. Almost all these vehicles still require fuel derived from crude oil to work.

4.1.6 Change in energy carriers for transport

Today, most of the final energy consumption (92.4%) that moves transport systems in the world comes from fuels derived from crude oil (petrol, diesel, kerosene, fuel oil and LPG), whose advantage is their high mass and volumetric density. However, their great disadvantage is their extremely negative environmental impact, which is becoming less acceptable at local (pollution of cities) and planetary scale (climate change). A total of 64.5% of final energy consumption of crude oil is used in transport, when this is the fossil fuel that is closest to exhaustion.

One of the greatest difficulties in the energy transition will be to roll out an alternative to crude oil that guarantees mobility. In most transport modes (road vehicles, ships and planes), an alternative energy carrier is required, which can be stored and has suitable mass and volumetric density to provide sufficient power and supply to meet today’s mobility needs. Fortunately, renewable energies exist that can meet these requirements.

Evidence seems to indicate that the renewable alternative to the current transport systems will be based on electric motors, powered by one of the following systems:

a) Electric batteries, which are used above all for transport in urban environments. Batteries tend to have excellent performance (in the order of 80% between charge and discharge). However, despite the progress in recent years, they have two disadvantages: they are heavy (in a standard car, every kilometre of range requires around 2 kg of battery) and expensive (each kilometre of range costs between €60 and 80).

b) Hydrogen from renewable sources and fuel cells, which are particularly suitable for heavy transport over long distances. Hydrogen enables sufficient energy to be stored on a vehicle for long journeys, but with a mass and volume (including the tank) that are greater than those of oil derivatives. The disadvantage is low efficiency in the conversion of electricity to hydrogen and back to electricity (in the order of 35%). Today, renewable hydrogen technology is still not commercially operational, but the European Commission and the Joint Research Centre (JRC) are promoting its development in Europe ([FCH-2014], [FCH-2015]).

c) Trolley poles and wires for the main railways and, possibly, for high-traffic roads. The efficiency of trolley wires could be relatively high, but fluctuations in demand may require storage (with the corresponding loss of efficiency) in a renewable electricity system. Today, tests are being undertaken on introducing double trolley wires to roads for heavy vehicles.

Despite losses in storage systems, electric motors are much more efficient (from 80 to 95%) than combustion engines (from 20 to 35%). Therefore, less energy is required to achieve the same amount of mobility.

Biofuels from crops cannot be the transport solution: if all the crops in the world were converted into biofuels, we would obtain approximately 30% of the crude oil that is extracted from underground today, and we would not have any human food [Riba-2011]. However, a limited number of vehicles (agricultural, public works, ships and planes) could function with combustion engines powered by biofuels from crops or organic waste.

In transport, most energy is consumed by the energy carrier (fuel, electricity or hydrogen) that propels the vehicles. However, other factors to consider are the production of the energy carrier, the construction and maintenance of vehicles (cars, lorries, trains, ships and planes) and infrastructure (roads, railways, ports and canals, airports, oil pipelines and gas pipelines), and the management of the system. When all the transport components are considered, the overall energy consumption could be between 30 and 60% higher than that of the energy carrier, depending on the transport mode. Therefore, transport uses a considerable proportion of final energy that can reach 40% in the world, 50% in OECD countries and 60% in countries such as Spain and Catalonia.

It is essential to raise public awareness about the impact on our lives of the progressive exhaustion of fossil fuels and crude oil. For the new concept of accessibility, we need to rethink and recover the idea of proximity in many face-to-face activities and, when appropriate, replace physical accessibility (mobility and transport) with virtual accessibility (information and remote actions). New synergies must be established between physical accessibility and virtual accessibility though a holistic approach.

4.2 Responsibilities and opportunities of the UPC

The Universitat Politècnica de Catalunya (UPC) has outstanding competences in these fields of activities. In the area of physical accessibility, its work covers vehicles, infrastructure and the organisation and management of passenger and goods transport; in the area of virtual accessibility it addresses transmitters, receivers and communication networks, computers and servers, computer programmes and applications, and the organisation and management of communication. As a leading technical university in a developed country, it has the responsibility (and the opportunity) to get actively involved and promote the changes required for the *transition to a new energy model*.

The activities of the Universitat Politècnica de Catalunya and its members in education, research, collaboration outside the university and participation in the general debate in the field of accessibility could be focused on the following areas:

4.2.1 Undertake studies on mobility

If the University is to guide the energy transition in relation to the mobility of passengers and goods, it must have sufficient, accurate knowledge of the situation, needs and desires of the population and how they evolve. People's mobility needs must be monitored and assessed continuously, according to the type of population and the activities (work, education, shopping, services, family and social relations, and leisure). The requirements for mobility of goods must also be examined (primary products, provisions for companies, water and electricity supplies), and "last mile distribution" in particular.

We should adopt a general approach that integrates all elements of transport: not just the energy carriers that move vehicles or drive fluids in tubes, but also the production of these vectors, vehicle manufacture and maintenance, and the construction, maintenance and operation of infrastructure. Furthermore, the analysis should include the impact of how these activities are organised and managed.

4.2.2 Research on power supply

From the perspective of the energy transition, most studies conclude that vehicles will be driven by electric power in the future, apart from some special applications. The power supply will be based on: *a*) batteries, *b*) hydrogen and fuel cells, *c*) trolley poles and wires. Globally, the most mature system is that of battery power: electric vehicles and plug-in hybrids reached 1.26 million units in 2015 [IEA-2016b] (out of a global number of around

1.28 billion cars in use). The network of electric vehicle charging stations is also expanding.

Batteries

Battery-powered electric vehicles have their greatest potential for mobility in urban areas: low speeds with frequent stops, short distances, lower battery requirements (less mass and lower cost) and frequent charging (in some cases, fast charging). Electric motorcycles and above all electric or power-assisted bicycles could be very interesting options to shape urban mobility in the future.

Current electric vehicles with lithium ion batteries (normally of 20 to 25 kWh) generally enable a vehicle to travel between 100 and 150 km on a full charge, but the range is gradually increasing. In a decade, the energy density has increased from 75 to 275 kWh/L and the price has decreased from 1,000 to 250 US$/kWh. Other problems that must be improved in this technology are charging time, durability and, in the near future, end of life.

Hydrogen and fuel cells

For heavy and long-distance transport (lorries, trains on non-electrified rails, ships and occasionally planes), the most suitable energy carrier appears to be hydrogen from renewable sources (today, almost all hydrogen is obtained by steam reforming from natural gas) or derived fuels. This requires the large-scale development of renewable hydrogen production technologies from hydrolysis of water, transformation of agricultural waste or photocatalytic hydrogen production directly from sunlight. In addition, fuel cells need to be promoted.

Without the development of hydrogen technology, the energy transition in transport will be hard pressed to reach beyond 50%. The European association *Fuel Cells and Hydrogen Joint Undertaking* (FCH-JU) is promoting research and development into hydrogen production by hydrolysis [FCH-2014] and fuel cells [FCH-2015]. The UPC has considerable responsibility in this area, as well as the opportunity to launch a pilot scheme on hydrogen to advance and prepare its future implementation on a larger scale, as a vital part of the energy transition in mobility.

Electric power via trolley poles and wires

Today, the first trials on electrification of roads are being undertaken, particularly on major roads. This is a viable option to explore that has an interesting predecessor in electrified railways. The efficiency of the system is greater than that of fuel cells.

Biofuels

For vehicles that operate off-road and require high power (farm tractors, public works machinery, machinery for working in forests, and possibly fishing boats or planes), limited production of biofuels from crop, animal or urban waste could be considered, if it does not interfere with human food.

Therefore, the UPC's areas of work in this field could be:

4.2.3 Research on vehicles and infrastructure

The *transition to a new energy model* in the area of transport would also have an impact on vehicles and infrastructure, as analysed below.

Urban transport

Private vehicles, which account for 15% of transport activity, are responsible for 40% of energy expenditure and emissions (in OECD countries, these percentages rise to 50% and 65%, respectively). From the perspective of the *transition to a new energy model*, this state of affairs should be changed. One way to have an impact is to promote public transport whenever feasible and promote shared vehicle solutions. However, in addition to these social aspects of mobility, the concept of vehicles should also be changed.

Many cars today are designed for uses that are not generally effective (off-road, long distance, sport driving or speeds that are prohibited by law) and therefore include features that influence their size, weight, cost and energy consumption. Given that the first steps towards the energy transition will be taken in relation to mobility in cities, we should start by redefining the battery-powered urban electric vehicle.

The same argument could be applied to goods transport, and particularly to distribution (or the last mile, which accounts for over 20% of this transport). Distribution is the most expensive step in energy terms, and should also be based on battery-powered electric vehicles.

Heavy and long distance transport

Transport of heavy loads over long distances requires power and energy storage greater than that provided by batteries, so a second phase of the energy transition must be tackled. Through its capacity to advance research, the university must fine-tune alternative systems. Rail transport should be promoted, as this is the most efficient system from an energy perspective. Where rail transport is not possible, electric vehicles powered by hydrogen and fuel cells could play a key role.

Transformation of infrastructure

Infrastructure is the element of mobility systems that requires the greatest investment (although the investment is recovered over the course of many years), and is the most difficult to adapt or transform. Therefore, we must study carefully how to adapt current infrastructure to future mobility needs from the perspective of the energy transition.

To promote public transport and the distribution of goods, which are the areas where the most benefits can be obtained from an energy perspective, it is vital to find suitable solutions for transport hubs where goods or passengers are transferred between vehicles or change mode in mobility systems. This can be achieved through careful design of infrastructure and civil society participation.

4.2.4 Research on transport planning and management

The planning and management of transport systems is a factor that can bring together all the elements that make the physical accessibility of people and goods possible.

Private vehicles provide freedom, but their excessive number has become one of the main problems today, and traffic and parking affect life in cities. The enormous number of private cars (907 million in the world, 22 million in Spain, and 3.3 million in Catalonia in 2014) use an unreasonable amount of resources and energy.

From the perspective of the energy transition, these figures indicate that we need to consider other ways of managing mobility, such as small vehicles, fleets of shared vehicles, a combination of taxi and bus, and coordinated systems for goods delivery. We must take into account the time and cost invested in managing and maintaining private vehicles, and the actual amount of time that they are used.

The other area that requires a great effort is the promotion and efficiency of public transport as a public service. It is essential to focus on two aspects: making these forms of transport attractive to the general public, and increasing and balancing the occupancy rate. Despite crowds during rush hour, the overall occupancy rate of public transport tends to be between 15 and 30% of capacity.

The planning and management of goods transport is overlooked by much of the general public, but it affects an essential part of mobility. In general terms, we should promote intermodal transport and increase the load factor, as there is no point in moving empty vehicles. Transport over the last mile is particularly important.

4.2.5 Synergies between physical and virtual accessibility

Virtual accessibility, information flows and communication systems are an increasingly integral part of all aspects of life. However, there are no studies on this subject comparable to those on physical accessibility, mobility and transport. Major advances have been made in technologies, but an even greater effort must be made in social and environmental studies.

Compared to other activities and particularly to physical accessibility, information and communication technologies (ICT) have two main effects on energy resources and greenhouse gas emissions:

a) Like all human activities, ICT require materials (often elements that are very rare on Earth) and energy that have been associated with 1.3 $GtCO_{2e}$ or 2.3% of global emissions in 2020, according to the report [GeSI-2012].

b) ICT have the potential to dematerialize other human activities and reduce energy use by 9.1 $GtCO_{2e}$ or 16.5% of overall emissions in 2020, according to the report. Out of this cut in emissions brought about by ICT, 1.9 $GtCO_{2e}$ correspond to improvements in transport.

This is an aspect that already plays an important role in improving accessibility by using fewer resources. Some university research groups are working on these aspects, but the possibilities are even greater in the general concept of accessibility. Therefore, it is of great interest to investigate this knowledge area further.

Some aspects that the UPC could address are described below.

4.3 Future areas of work of the UPC

A series of future areas of work is proposed that the UPC wishes to, can and must adopt to respond to the challenge of the *transition to a new energy model* in the area of Accessibility, Mobility and Energy.

A. Through **cross-cutting activities** (advance research, test new solutions, participate actively in the general debate and train future generations), the University will work on key aspects such as:

   - The idea of mobility as a basic service, according to new integrating concepts.
   - Analysis and study of existing infrastructure (electrification of roads, among others).
   - Planning and management of public transport and goods transport (transport interchanges, load factors, the last mile, etc.)
   - Innovative forms of transport.

B. The University will undertake the following **specific actions** in this area:

   I. Offer the Government of Catalonia (and other governments) the capacity to undertake or participate in the analysis and continuous monitoring of the development of mobility.
   II. Develop new concepts of battery-powered urban electric vehicles (bicycles, motorbikes, cars and vans) and promote supporting technologies.
   III. Promote research and development of hydrogen as an energy carrier. Make the UPC a pilot for testing the production of hydrogen from renewable electricity, storage and charging systems, and vehicles with fuel cells.
   IV. Promote studies on the circumstances in which physical accessibility, virtual accessibility or a combination of the two are most suitable and develop new forms. Identify barriers to the various forms of accessibility.

5. Information, communication and energy

Contents

5.1 Analysis of the situation and trends

5.1.1 Information, communication and energy

Information and communication technologies (ICT) have become essential in our time, up to the point that we do not realise how much they are part of our lives. From when we get up in the morning, we are surrounded by connected devices that capture data, process them, transmit them and act on them. Highly complex ICT systems manage public transport while the passengers check the latest news, reply to emails or have chats on their mobile phone screens. Laptops have become common in schools, electronic medical records improve monitoring of patients' health, bank services can be accessed merely by remembering a 4- or 6-digit number or putting a card near to a terminal, and culture is disseminated in social networks.

ICT are fully established in our lives and concepts such as the smart city, the internet of things (IoT), e-commerce or streaming attract the attention of the economic and political spheres and therefore the technology sector.

In 2012, it was estimated that the electrical energy used in ICT systems stood at around 900 TWh or 4.6% of the world's electricity. The annual increase was 7%, which is double the annual increase in electrical energy consumption in the world (3.4%) [Lannoo-2013]. Therefore, the energy consumption of ICT systems is going up, in line with the increasingly extensive use of ICT technologies. In fact, ICT are responsible for 8 to 10% of European electricity consumption and 4% of its CO_2 emissions [ICTfottprint-EU-2017].

The first computer that could store and execute a programme was the Univac 1101, which was launched in 1950. Since then, more or less every 15 years a revolution has occurred that has changed not only the world of computer science, but also business and society itself. In 1965, the first corporate computers, called mainframes, emerged and companies began to adopt computer systems to do tasks that had previously been impossible or too expensive. These computers could only be afforded by large corporations (banks, insurers and multinational companies). In 1980, the first personal computer (PC) appeared, which brought computing into small business and homes. In 1995, the internet was launched, and brought with it a revolution. Although less known to the general public, in 2010 another step was taken with the first large data centres that, due to their calculation possibilities, open the way for progressive transformation of society. Concepts such as big data, data mining, social networks or green computing are the order of the day.

In his book *The Zero Marginal Cost Society* [Rifkin-2014], the economist and sociologist Jeremy Rifkin states: "Throughout history, great economic transformations occurred when human beings discovered new energy regimes and created new communication media to organize them". He continued: "In the nineteenth century, steam-powered printing and the telegraph became the communication system for linking and managing a complex coal-powered rail and factory system, connecting densely populated urban areas across national markets. In the twentieth century, the telephone, and later, radio and television, became the communication media for managing and marketing a more geographically dispersed oil, auto and suburban era and a mass consumer society. In the twenty-first century, the Internet is becoming the communication medium for managing distributed renewable energies and automated logistics and transport in an increasingly interconnected global Commons".

For example, when we purchase an object virtually using our mobile phone, hundreds of devices are involved. The terminal that we have in our hands is connected via its antenna to a point of access, which converts electromagnetic waves into an electric current that carries information on who we are, where we are and what we want; numerous interconnected routers pass our message from one point to another in the network until it reaches the supplier's servers; the storage systems that contain exabytes of memory (EB = 10^{21} bytes) save a copy and the purchase process is started with continuous exchanges of information between our bank, the order manager and the package deliver services. For just one electronic transaction, thousands of electronic chips process and exchange information, consuming energy at each step.

Therefore, when we analyse the relationship between information and communication technologies and energy, we find that it is a highly complex problem. Indeed, it is very difficult to estimate the energy required to power the billions of devices that are involved in the production, storage, transport, processing and display of data. To achieve this accurately, we must take into account numerous aspects that are analysed in the sections of this chapter [Mills-2013].

In addition, we must take into account the process of destroying/dismantling the electronic material and the design, considering the concept of a circular economy (cradle to grave versus cradle to cradle), which is also analysed below.

5.1.2 The manufacture of ICT devices

Unlike many other products and systems, one of the most notable aspects of electronic devices used in information and communication technology is that the energy required for their manufacture, which is known as embodied energy, tends to be much greater than the energy the devices require during their use [Williams-2004].

For example, for 2 megabytes (MB) of memory, 80% of the energy is consumed during manufacture, while only 20% is consumed during the product's expected four years of life. This is due to the fact that micro- or nanoscale systems inherently have very low entropy, and therefore require considerable energy in their manufacture [Mobbs-2010]. There is no technological solution to resolve this problem: it is a fundamental principle of physics. The production process can be improved, but we cannot avoid the large amount of energy required to reduce the entropy.

As a conservative estimate, the amount of embodied energy required to manufacture a mobile phone is 0.25 GJ (gigajoule = 10^9 joule), while to manufacture a tablet it is 1.0 GJ, and to make a laptop it is 4.5 GJ. Therefore, the energy consumed by the annual production of these devices is over 1 EJ (exajoule = 10^{18} joules; or around 2,800 GWh). In addition, most of these devices are made in Asian countries where electricity mainly comes from coal power stations, and then distributed worldwide on ships fuelled by oil.

Apple [Apple-2016] stated that out of the tonnes of CO_2 that it generates (mainly through electricity consumption), 77% are due to the manufacture of products, 4% to transport and only 17% for own use, even though Apple's data centres in North Carolina, Nevada and Oregon operate on 100% renewable energies.

5.1.3 High diffusion of user devices

An enormous number of devices are in use, including personal computers (PCs), laptops, smartphones, tablets, smart televisions and routers. In 2015, the number of mobile phones was higher than the number of people in the world, at over 7.3 billion units [Ditrendia-2015]. Every day, new devices appear on the market to replace existing ones, due to real, built-in or style obsolescence. In 2015, over 1 billion mobile phones were sold, 230 million tablets and 60 million laptops [IEEE-2016]. The capacity of a typical battery in a current smart phone is between 2000 and 4000 mAh (milliampere hours). Battery consumption depends greatly on the mode of use, but a conservative estimate is that most users consume about 60% of battery capacity per day, which must then be recharged. In Spain alone, with 20 million mobile phones in use, this corresponds to around 44 GWh per year. At global scale, personal computers (PC) and their screens alone use 40% of the energy consumed by information and communication technologies and emit 0.8% of the world CO_2.

5.1.4 Widespread communication networks

Other systems that consume high levels of electricity are the widespread wireless and non-wireless broadband communication networks.

The International Energy Agency estimated for 2014 that devices connected to the network in standby mode consumed over 600 TWh [IEA-2014]. This is before the phenomenon of the internet of things (IoT) has taken off, which will usher in a world in which all devices are connected. It is no surprise, then, that the G20 leaders agreed at a meeting in November 2014 that one of the six priorities in their Energy Efficiency Action Plan is related to devices connected to the network [G20-2014]. The typical wattage of routers is between 7 and 18 W [Mitchell-2016] [TPCDB-2017], and their energy use worldwide is estimated to be 52 TWh per year [Nokia-2012]. A high percentage of these devices, which are present in 80% of homes, are permanently connected and consume energy.

The increase in demand for network capacity and coverage also implies greater consumption of energy by infrastructure suppliers and network operators. In 2012, it was estimated that operators' network equipment consumed 260 TWh [Nokia-2012]. The same year, the main operators reported annual increases in energy consumption of between 15 and 35%. The penetration of mobile communications is expected to reach 100% of the world population in 2020, and each user is estimated to consume between 25 and 50% more data each year.

Today, these figures will be much higher due to the introduction of cloud computing and the proliferation of services based on remote servers, such as virtual assistants or some applications for mobile devices. An increase in penetration of the internet of things (IoT) [EPRS-2016] is expected, which will push up data consumption, leading to 27% accumulated growth between 2015 and 2020 [Cisco-2016].

When they are considered individually, internet of things (IoT) devices consume little power (between μW, microwatt = 10^{-6} watt, and mW, milliwatts = 10^{-3} watt). However, as billions of units are likely to be introduced worldwide, the overall annual consumption will be in the order of GWh. This is without taking into account the impact of the resulting increase in data for suppliers of network and data processing services, or the problem of managing billions of rechargeable batteries and recycling them at the end of their useful life.

Most electronic devices spend much of the time on standby, waiting for an interaction with the environment. This is particularly relevant for systems such as the internet of things (IoT), but also for smart phones, routers and domestic electrical appliances such as TVs, video recorders and sound centres. The overall contribution of this kind of energy consumption is considerable: in the order of 23% of the domestic energy bill in households according to a study [NRDC-2015] undertaken in 2015 on households in northern California. This consumption is due partly to technologies, specifically the characteristics of electronic circuits, and partly to design decisions that do not consider energy consumption a priority.

5.1.5 Data centres

Data centres ensure our information is accessible at all times, and account for the same level of greenhouse gas emissions as aviation [GeSI-2012]. It has been estimated that a simple email emits 4 g of CO_2 or 50 g if it has a document attached [Berners-Lee-2010]. The International Data Corporation [IDC-2017] forecast that in 2020 around 40 ZB of information (ZB, zettabyte = 10^{21} bytes) will have been stored in the world, or 40 billion hard drives of 1 TB (TB, terabyte = 10^9 bytes), each one of which tends to consume between 4 and 8 W (0.5 W if it is in standby or sleep mode). Although we do not know the exact figures, it has been estimated that in 2016, there were over 100 million physical servers in the world, of which over a million belonged to Microsoft and Google. In 2013, data centres in the USA consumed 91 TWh (around 2.2% of the total energy generated in the country) and it is forecast that in 2020 they will consume 3.5%. In addition, it has been calculated [IEEE-2016] that communication networks consumed 5% of the energy generated in 2012, and will consume 10% in 2020.

The residential electricity consumption of the inhabitants of Catalonia in 2014 was 1,280 KWh per inhabitant per year [Idescat-2017c]. A typical data centre consumes around 50 MW, which is equivalent to the residential consumption of 375,000 Catalans (5% of the population). In fact, the supercomputer MareNostrum installed in the UPC has peak consumption of 28 kW [BSC-2017].

5.1.6 ICTs and opportunity costs

Energy consumption is determined not only by the physical limitations of ICT technology, but also to a great extent by design decisions regarding access to resources, that is, software [Singh-2015] [Zhang-2014]. Unfortunately, most software developers do not know the impact of their software on energy consumption [Pang-2016]. This impact is due to operation, the algorithms used in the interaction with the operating system, and higher-level decisions, such as how often the network resources are accessed or software updated, which leads to consumption of energy in the device itself and in all elements of the network that are involved.

However, the expansion of ICTs does not necessarily mean that there will be an increase in energy consumption and global pollution. In 2008, the Global e-Sustainability Initiative (GeSI) published the first major report on ICT capacity to contribute to creating a low carbon economy and promoting sustainability from a holistic perspective [GeSI-2008]. The report included the impact in the ICT sector and its beneficial effects on other sectors. In 2012, the SMARTer-2020 report was published [GeSI-2012] and in 2015, the SMARTer-2030 [GeSI-2015] report.

The SMART-2020 [GeSI-2008] report estimated that emissions caused by ICT would increase from 0.5 $GtCO_{2e}$ (billion tonnes of CO_2 equivalent) in 2002 out of a total of 40.0 to 1.43 $GtCO_{2e}$ in 2020 out of an estimated 51.9. The report also indicated that ICT have the potential to reduce emissions in other sectors by 7.8 $GtCO_{2e}$, which is 5.5 times more than the emissions that ICT generate. The subsequent SMARTer-2020 [GeSI-2012] report reduced the estimated emissions caused by ICT to 1.27 $GtCO_{2e}$ in 2020 and increased the potential to reduce emissions in other sectors to 9.1 $GtCO_{2e}$ (7.2 times). Note that the percentage of CO_{2e} emissions in the sector are indicators of energy consumption.

The third report, SMARTer-2030 [GeSI-2015], cut the emissions caused by ICT to 1.25 $GtCO_{2e}$ in 2030 and estimate that if ICT solutions are introduced in the entire economy, emissions in other sectors could be reduced by 12.1 $GtCO_{2e}$ (9.7 times), that is, a reduction of 20% of the global emissions of CO_{2e}. According to the report, ICT could effectively dissociate economic growth from the increase in emissions and generate an annual economy of around 9 billion euros (11 billion US dollars).

The analysis of these energy balances is a highly complex task that requires a methodology that still needs to be defined and agreed, as indicated at scientific conferences such as the International Conference on ICT for Sustainability.

In fact, many experts indicate that the most important aspect of information and communication technologies is their opportunity cost: ICTs provide various options for reducing energy consumption in other disciplines. The SMARTer-2030 [GeSI-2015] document includes the following examples: 1) improvement in mobility and logistics, and elimination of unnecessary journeys (reduction of 3.6 $GtCO_{2e}$ in 2020); 2) client-centred manufacture and circular supply chains (reduction of 2.7 $GtCO_{2e}$); 3) smart agriculture to increase productivity and reduce food wastage (reduction of 2.0 $GtCO_{2e}$); 4) smart buildings to save energy (reduction of 2.0 $GtCO_{2e}$); 5) integration of renewable energies and improvement of efficiency (reduction of 1.8 $GtCO_{2e}$).

5.1.7 Summary of the relationship between ICTs and energy

To sum up, information on the relationship between ICTs and energy is lacking, and many questions still need to be answered. However, some calculations and studies have been undertaken that begin to reveal the magnitude of the relationship:

Micro- and nanoscale systems inherently have very low entropy and their manufacture requires a lot of energy. The production process can be improved, but the large amount of energy needed to reduce the entropy (a principle of physics) cannot be avoided [Mobbs-2010].

The greatest energy cost of ICT and virtual accessibility systems is therefore in the manufacture of the electronic devices rather than in their use: for 2 MB of memory, 80% of the total energy is consumed in the manufacture, and 20% in the device’s use over four years of life [Williams-2004].

Most devices are manufactured in Asia where electricity is still generated mainly through coal power stations. They are then distributed worldwide in ships fuelled by oil.

Energy consumption by the data centres that maintain virtual accessibility is responsible for greenhouse gas emissions equivalent to those of aviation [GeSI-2012].

A more accurate analysis should be undertaken to determine the extent to which the internet of things (IoT) increases energy uses and CO_{2e} emissions or decreases them.

Other aspects that have a strong impact on energy uses and CO_{2e} emissions associated with ICTs depend more on social dynamics and behaviour than technologies. In this aspect, the induction of premature obsolescence through technological change or issues such as fashions is particularly relevant.

5.2 Responsibilities and opportunities of the UPC

5.2.1 UPC contributions to research and teaching

Energy consumption has been and continues to be one of the main objectives of research projects and course curricula in the area of information and communication technologies, particularly regarding the physical layers of communication. Some examples are antenna efficiency, the design of low-power integrated circuits, and energy harvesting for the internet of things (IoT).

Although all these topics are covered in curricula, a more general focus is probably required to educate the professionals who will lead the ICT industry in the problems described above. These are not only purely technological issues, but also design and awareness decisions that could have a profound impact on reducing energy consumption. Therefore, it is vital to continue to promote cross-cutting subjects and seminars on sustainability and ethics.

Service-learning activities should be incorporated into curricula. For example, the *UPC-Reutilitza* programme gets students involved in ICT and sustainability issues and helps them to lengthen the life of discontinued computers by repairing them, fine-tuning them and giving them to NGOs.

For many years, several UPC research groups have been working intensely on the manufacture of crystalline silicon cells, basically to develop more efficient manufacture techniques and cut costs. The UPC has specialised in Interdigitated Back Contact Solar Cells (IBC solar cells), which have two cell contacts on the back face, leaving the front face free of shadows [Savin-2015]. In the near future, this kind of cell is likely to play an important role in the photovoltaic market. At the UPC, 22% efficiency has been achieved using IBC solar cells, with back contacts manufactured by laser technology. Laser technology can simplify the process of manufacturing solar cells.

The same department is developing [Silvestre-2016] algorithms for automatic supervision of photovoltaic systems that can detect problems remotely and almost in real time. Remote monitoring uses new protocols and communication standards to assess the main parameters and identify potential errors in a photovoltaic system rapidly, and thus reduce losses in the energy that is generated.

The UPC is developing low-power processor architectures in the Barcelona Supercomputing Center, Department of Computer Architecture. In fact, the evolution of processors in recent years has been marked by an increase in performance per watt, with new proposals that can reduce the consumption of microprocessors and their memories. The most notable project in this field is the MontBlanc European project whose aim is to design technology for constructing a supercomputer that can obtain a performance of 1 exaflop with consumption below 20 MW.

At the UPC, routing protocols are being developed that can improve network efficiency by reducing the number of collisions and the amount of protocol data, and therefore the energy that is consumed [Vazquez-2015].

Other ICT and energy areas are being researched, focused on the design of ultra-low power electronic devices for digital and radiofrequency communication [Garcia-Leyva-2016], in energy harvesting circuits [Nunes-2016] and on-chip energy management circuits. In fact, high efficiency energy processing is achieved through ICT technologies.

The UPC is working on the design of devices and circuits that process electrical output generated with high energy efficiency using technological processes similar to those involved in ICT circuits. Control of these circuits is vital, among other reasons to adapt, with negligible losses, renewable energy production to consumption that could range from that of a communications satellite to that of an electric vehicle or injection into the grid.

In general terms, the aim is to consider the cross-cutting environments in which proposals are made (advance research, test new solutions, participate actively in the general debate, and train future generations) and to continue to study and boost these areas.

5.2.2 Development of ICT technologies

The development of information and communication technologies (ICTs) has some special characteristics that should be highlighted:

First, they are technologies that are clearly on the rise and growing faster than the rest of the sectors. ICTs have recently penetrated other systems and activities through data mining, big data and the internet of things (IoT). Therefore, their impact on energy and the environment is increasing.

Second, most of the energy consumption and environmental impacts are hidden as they are greater during the manufacture process than during use. Criteria and tools are needed to establish meaningful life cycle assessments.

Third, information and communication technologies use materials that are very scarce and expensive (rare earth elements and conflict minerals: cassiterite for tin, wolframite for tungsten, coltan for tantalum and gold ore ([Global-Witness-2009], among others) in very small quantities in each device (although these devices are produced in millions of units). However, there is still not enough awareness of the importance of managing the end of life of these devices (avoiding obsolescence, promoting second uses and recycling scarce materials).

In this section, we list improvements in information and communication technologies (ICTs) that could lead to greater efficiency and a lower impact of digital and analog devices, in their manufacture, their use, and when in standby mode.

5.2.3 Uses and management of ICT technologies

In their uses, information and communication technologies (ICTs) have contradictory impacts in terms of the resources they require and their environmental impacts. This makes it even more interesting to promote studies to further our knowledge of them:

a) Like all human activities, ICTs require resources (that are often very scarce on Earth) and energy (the [GeSI-2008] report estimated that ICTs will produce 1.4 $GtCO_{2e}$ or 2.8% of global emissions in 2020 and therefore will consume a similar proportion of energy).

b) However, ICTs also have the potential to dematerialize human activities and indirectly reduce emissions (according to the [GeSI-2008] report, by 7.8 $GtCO_{2e}$, 15% of global emissions in 2020) and therefore cut energy consumption by a similar proportion.

Suitable management of ICTs could mean that many superfluous or useless activities are avoided. Research into ICT security, both with respect to technical and human errors and outside attacks, is of great interest to ensure overall and energy efficiency in the production system.

In this section, we list forms of ICT use and management that, due to their impact on their own systems and interactions with other systems, lead to better results from social and technological perspectives.

5.2.4 ICTs and accessibility

As indicated at the start of the previous chapter (4. *Accessibility, mobility and energy*), accessibility to places, goods, services, information and knowledge, including physical accessibility through mobility and virtual accessibility through ICTs, is one of the basic values of humanity and is also an essential condition for participation of people and communities and social inclusion.

In the past, accessibility was based mainly on mobility. Today, information and communication technologies have an increasing impact on overall accessibility (physical and virtual), at times in collaboration with physical accessibility, at other times in competition with it or replacing it.

Although it is partly redundant considering the last section of the previous chapter, here we list areas of work of the UPC on accessibility, from the perspective of ICTs:

- Study and propose solutions to optimise all physical and virtual accessibility
- Promote forms of universal, virtual accessibility in all social sectors and all territories, to encourage people's participation and ensure social inclusion.

5.3 Future areas of work of the UPC

A series of future areas of work is proposed that the UPC wishes to, can and must adopt to respond to the challenge of the transition to a new energy model in the area of Information, Communication and Energy.

A. Through **cross-cutting activities** (advance research, test new solutions, participate actively in the general debate and train future generations), the University will work on key aspects such as:

- Costs and direct and indirect impacts of the life cycle of ICTs
- New recycling methods
- Optimisation of routing protocols
- New methods based on ICTs and low environmental impact
- Energy and environmental compatibility
- Safety of ICT systems

B. It will also undertake the following **specific actions** in this area:

I. Propose new methods and new materials to optimise the energy required to manufacture integrated circuits. Research new materials to manufacture electronic circuits that need less rare earth elements, highly contaminating materials and/or materials from conflict areas. Develop and improve energy harvesting techniques.

II. Analyse the opportunity cost represented by ICT involvement in savings and energy efficiency processes in sectors of activity, and assess the consequences of technical and human errors and external attacks on the overall and energy efficiency of the production system.

6. Technological processes and energy

Contents

6.1 Analysis of the situation and trends

6.1.1 Technological processes and useful energy

A technological process is an ordered, interlinked sequence of procedures that uses energy resources and material in combination with knowledge to obtain goods and services that are useful for people and communities. From an economic perspective, technological processes are grouped into sectors of activity.

Table 1.2 of Chapter 1 (and Table 6.1 of this chapter) show the total final consumption (TFC in the IEA balance sheets of fuel inputs and electricity, excluding non-energy uses) by end user according to the sector of activity. At global scale, the industrial sector accounts for the largest proportion of total final consumption, followed closely by the transport sector. The residential and service sectors, excluding transport, are responsible for a much smaller proportion of TFC, while the primary and non-specified sectors have a much lower energy impact.

However, what is ultimately of interest is useful energy: the energy that moves processes and machines, propels vehicles, heats building, and activates information and communication technologies. Between total final consumption and useful energy there are new conversions and losses in the users' own processes (through combustion gases, transmission lines and transformers, and above all exhaust gases from combustion engines), which result in useful energy being significantly lower than total final consumption.

Useful energy can be estimated from the total final consumption in IEA balances by applying an average efficiency of 80% for heating and electrical end uses, and 25% for mobility end uses (Table 6.1). This results in global useful energy for 2014 of 59,910 TWh/year, which is 59.9% of total final consumption and 40.4% of primary energy (almost 60% of the energy is lost on the way).

An analysis of useful energy distribution in the world by sector of activity reveals the notable position of industry at 42.0% (10.0 percentage points higher than its proportion of total final consumption), followed by the residential sector at 30.0% (up 6.1 percentage points). There is also an increase in the service sector at 11.5% (up 2.8 points). In contrast, useful energy in the transport sector is down to only 12.9% of the total, which is 17.7 percentage points less than the total final consumption.

To a greater or lesser extent, these relationships are found in all geographic areas and are due to the fact that most energy losses in transport occur in the thermodynamic processes of combustion engines in users' vehicles. This is good news for the energy transition in transport (that is currently highly dependent on oil), as electrical mobility requires 3 to 4 times less energy than that of current fuels.

Table 6.1 Estimated useful energy by geographical areas and sector of activity (2014)							
		World	OECD	Non-OECD	EU28	Spain	Catalonia
Population	10^6 inhabitants	7.265	1.270	5.995	505	46,8	7,5
	% world	100,0 %	17,5 %	82,5 %	6,9 %	0,64 %	0,10 %
Primary Energy (PE)	**TWh/year**	**148.140**	**58.720**	**89.410**	**17.930**	**1.410**	**265**
Per capita	kWh/(inhab·yr)	20.390	46.190	14.910	35.500	30.160	35.230
	% world	100,0 %	39,6 %	60,4 %	12,1 %	0,95 %	0,18 %
Total Final Consumption(TFC)	**TWh/year**	**99.980**	**40.090**	**59.890**	**12.570**	**1.000**	**175**
Per capita	kWh/(inhab·yr)	13.760	31.530	9.990	24.910	21.360	23.140
	% PE	67,5 %	68,3 %	67,0 %	70,1 %	70,8 %	65,8 %
	% world	100,0 %	40,1 %	59,9 %	12,6 %	1,00 %	0,17 %
Agricult., fishing	% TFC	2,3 %	1,9 %	2,6 %	2,3 %	3,2 %	2,7 %
Industry	% TFC	32,0 %	23,5 %	37,7 %	23,6 %	22,4 %	23,7 %
Services	% TFC	8,7 %	13,9 %	5,1 %	13,0 %	10,3 %	10,6 %
Transport	% TFC	30,6 %	39,9 %	24,3 %	36,3 %	46,0 %	49,9 %
Residential	% TFC	24,9 %	20,0 %	28,2 %	24,3 %	17,1 %	13,1 %
Not specified	% TFC	1,5 %	0,8 %	2,1 %	0,4 %	1,1 %	0,0 %
Useful Energy (UE)	**TWh/year**	**59.910**	**22.610**	**37.300**	**7.310**	**528**	**89**
Per capita	kWh/(inhab·yr)	8.250	17.810	6.220	14.480	11.280	11.850
	% TFC	59,9 %	56,4 %	62,3 %	58,1 %	52,8 %	51,1 %
	% PE	40,4 %	38,5 %	41,7 %	40,8 %	37,4 %	33,6 %
	% world	100,0 %	37,7 %	62,3 %	12,2 %	0,88 %	0,17 %
Agricult., fishing	% TFC	1,9 %	1,4 %	2,1 %	1,9 %	2,9 %	1,6 %
Industry	% TFC	42,0 %	32,5 %	47,7 %	31,7 %	33,4 %	36,7 %
Services	% TFC	11,5 %	19,7 %	6,5 %	17,8 %	15,5 %	16,5 %
Transport	% TFC	12,9 %	17,7 %	10,0 %	15,9 %	22,0 %	24,8 %
Residential	% TFC	30,0 %	27,7 %	31,3 %	32,2 %	24,8 %	20,3 %
Not specified	% TFC	1,8 %	1,0 %	2,4 %	0,4 %	1,4 %	0,0 %

PE = Primary Energy; TFC = total final consumption; UE = useful energy. Non-energy uses have been excluded.
***Sources**: World, OECD, Non-OECD, European Union (EU28) and Spain [IEA-2016]; Catalonia [Idescat-2017a]*

In 2014, industry consumed 32.5% of useful energy in OECD countries, 47.7% in non-OECD countries that are the factory of the world, 31.7% in the EU28, 33.4% in Spain and 36.7% in Catalonia. Residential uses accounted for 27.7% of the total useful energy in OECD countries (the percentage is lower due to high consumption in transport), 31.2% in non-OECD countries, 32.2% in EU28, 24.8% in Spain and 20.3% in Catalonia (a very low value, probably due to the mild climate and the high impact of transport). The industrial and residential sectors together consume 72.0% of useful energy at global scale (almost three quarters of the total), 60.2% in OECD countries, 79.0% in non-OECD countries, 63.9% in the EU28, 58.2% in Spain and 57.0% in Catalonia.

In Catalonia, the variation between final total consumption and useful energy is considerable, due to the high proportion of transport in the energy mix. The percentage of useful energy consumed by industry is 13.0 points higher than the total final consumption and is the highest percentage of all sectors (36.7%).The percentage of useful energy consumed in the residential and service sectors is 7.2 and 5.9 points higher than the total final consumption respectively, while that of transport is 25.1 points lower and is in second place (24.8%). The general public sometimes assume that overall energy uses resemble residential uses, when residential uses only account for a small proportion of total consumption.

In the EU28, the useful energy consumption per capita dropped between 1990 and 2014 from 16,570 to 14,470 kWh/(inhab·year), of which the useful energy consumed in homes fell from 5,220 to 4,470 kWh/(inhab·year). In contrast, in Spain the useful energy consumption per capita increased between 1990 and 2009 from 9,530 to 12,280 kWh/(inhab·year) and that of households rose from 2,060 to 3,050 kWh/(inhab·year). However, as in the rest of Europe, from 2009 to 2014 the useful energy consumption per capita dropped to 11,290 kWh/(inhab·year) and that of households to 2,980 kWh/(inhab·year).

Notably, electrical and mobility uses have increased. In mobility, "fuels" are the proportion of fossil fuels (mainly derived from crude oil) that are used in internal combustion engines (Table 6.2). The increase in mobility and electrical uses cut the efficiency of conversions of primary to useful energy in the world from 43.2% in 1990 to 40.4% in 2014, due to the dissipating effects of electricity generation and vehicle propulsion when derived from fuels. To a greater or lesser extent, this pattern can be found in all geographic areas. In Catalonia, conversion efficiency dropped from 39.7% in 2005 to 33.6% in 2014 (based on [Idescat-2017a]).

Table 6.2 Evolution of the % of electricity and fuels in final energy (2014)

Year	WORLD		OECD		Non-OECD		EU28		Spain		Catalonia	
	Electr.	Fuel	Electr.	Fuel	Electr.	Fuel	Electr.	Fuel	Electr.	Fuel	Electr.	Fuel
1990	14,4 %	29,2 %	18,8 %	37,7 %	9,8 %	20,6 %	17,9 %	32,7 %	18,2 %	45,5 %		
2005	18,0 %	32,3 %	22,0 %	40,7 %	14,2 %	24,2 %	19,8 %	35,6 %	19,9 %	47,0 %	22,1 %	48,1 %
2014	19,8 %	31,8 %	23,3 %	41,1 %	17,6 %	25,6 %	21,5 %	37,3 %	22,7 %	47,6 %	23,6 %	51,8 %

The percentages of fuels do not coincide with those of transport, as fuels are also used in agriculture, fishing and non-specified sectors that are accounted for in the financial years. Sources: [IEA-2016], [Idescat-2017a]

6.1.2 Thermal, mobility and electrical uses and useful energy

In addition to analysing energy uses at the three levels of energy (primary, final and useful) by sector of activity (industry, services, residential, transport and others), it is interesting to observe the distribution of useful energy in terms of thermal, mobility and electrical uses (Table 6.3).

Table 6.3 Distribution of useful energy between thermal, mobility and electrical uses (2014)

	WORLD			OECD			Non-OECD		
	Thermal	Mobility	Electrical	Thermal	Mobility	Electrical	Thermal	Mobility	Electrical
Total sect.	**60,4 %**	**13,5 %**	**26,1 %**	**49,1 %**	**18,3 %**	**32,6 %**	**67,2 %**	**10,6 %**	**22,1 %**
Primary sec.	33,2 %	17,3 %	49,5 %	20,9 %	25,4 %	53,7 %	37,3 %	14,7 %	48,0 %
Industry	73,2 %	0,0 %	26,8 %	67,5 %	0,0 %	32,5 %	75,5 %	0,0 %	24,5 %
Services	49,1 %	0,0 %	51,1 %	47,0 %	0,0 %	53,0 %	52,8 %	0,0 %	47,2 %
Transport	0,0 %	100,0 %	0,0 %	0,0 %	100,0 %	0,0 %	0,0 %	100,0 %	0,0 %
Residential	76,1 %	0,0 %	23,9 %	62,7 %	0,0 %	37,3 %	83,3 %	0,0 %	16,7 %
	EU28			Spain			Catalonia		
	Thermal	Mobility	Electrical	Thermal	Mobility	Electrical	Thermal	Mobility	Electrical
Total sect.	**54,6 %**	**16,5 %**	**29,0 %**	**43,3 %**	**22,9 %**	**33,8 %**	**37,9 %**	**26,0 %**	**36,1 %**
Primary sec.	47,3 %	26,8 %	25,9 %	42,4 %	22,3 %	35,4 %	3,6 %	75,4 %	20,9 %
Industry	65,6 %	0,0 %	34,4 %	67,5 %	0,0 %	32,5 %	60,2 %	0,0 %	39,8 %
Services	50,5 %	0,0 %	49,5 %	31,4 %	0,0 %	68,6 %	24,6 %	0,0 %	75,4 %
Transport	0,0 %	100,0 %	0,0 %	0,0 %	100,0 %	0,0 %	0,0 %	100,0 %	0,0 %
Residential	73,3 %	0,0 %	26,7 %	56,7 %	0,0 %	43,3 %	57,4 %	0,0 %	42,6 %

Percentages of the total energy uses in each sector. Sources: [IEA-2016], [Idescat-2017a]

The first refer to explicitly thermal uses (heat obtained from burning fuels and solar thermal energy); the second to energy for vehicle propulsion (fuels and a small fraction of electric traction); and the third to uses channelled through electricity (excluding electric traction) that are basically: lighting, domestic electrical appliances (including cookers, water heaters and electric heaters), electronic, information and communication devices, machine drives and other processes in industry and services that are based on electricity (electric resistance heating and induction furnaces).

In 2014 at global scale, 60.4% of useful energy consumption was for explicitly thermal uses, just over a quarter (26.1%) was based on electricity, and only 13.5% on mobility. Since 1990, the percentage of electrical uses worldwide has risen 7.8 points and the percentage of mobility uses has gone up 1.1 points; these percentages are subtracted from thermal uses. The two sectors of activity that are the greatest consumers of energy clearly tend towards thermal uses: the residential sector (76.1%) and the industrial sector (73.2%). The service sector has almost equal distribution of uses (49.1% thermal and 50.9% electrical), while in transport all uses are related to mobility. Since 1990, there has been an increase in the percentage of electrical uses in services (up 13.2 points), the residential sector (up 8.1 points) and industry (up 5.4 points).

The percentages for electrical uses in the service, residential and industrial sectors in OECD countries (53.0%, 37.3% and 32.5%, respectively) are higher than in non-OECD countries (47.2%, 16.7% and 24.5%, respectively); with a considerable difference of over 20 points in the residential sector. Catalonia (more than Spain and Europe) has particularly high electrical uses (75.4% in services, 42.6% in the residential sector and 39.8% in industry), partly due to less intensive use of heating.

6.1.3 Industrial processes with high energy use

Industry is the sector that consumes the most useful energy, so it is important to analyse which of its subsectors are the greatest consumers. Table 6.4 shows the total final consumption and useful energy in industry for the EU28 and Spain [IEA-2016] and for Catalonia [Idescat-2017a], as well as the percentage distribution of total final consumption among the main industrial subsectors in the EU28 and Spain [Eurostat-2017] and Catalonia [ECESI-2011].

Table 6.4 Total final consumption in industry and its subsectors

Industrial sector and subsectors	EU28 (2014)		Spain (2014)		Catalonia (2011)	
	TFC TWh	Electricity %	TFC TWh	Electricity %	TFC TWh	Electricity %
Industria (total final consumption)[1] % TFC	**2.980** 23,6 %		**223,6** 22,4 %		**41,2** 23,7 %	
Industry (useful energy)[1] % total useful energy	**2.320** 31,7 %	33,5 %	**176,2** 33,4 %	32,9 %	**32,6** 36,7 %	37,8 %
Chemical and petrochemical	19,3 %	31,6 %	20,8 %	20,2 %	27,5 %	40,3 %
Glass, ceramic and cement	12,6 %	18,0 %	16,6 %	15,5 %	19,6 %	14,2 %
Food and tobacco	10,4 %	36,7 %	10,7 %	46,7 %	16,8 %	35,8 %
Paper and graphic arts	11,0 %	29,7 %	8,9 %	30,1 %	10,1 %	32,9 %
Metal processing	9,9 %	57,9 %	6,2 %	61,1 %	8,1 %	62,7 %
Steel and metal	23,1 %	26,2 %	19,7 %	50,6 %	7,4 %	51,1 %

[1] The values of energy uses in TWh are given in bold.
Sources: EU28 and Spain, [IEA-2016] i [EUROSTAT-2016]; Catalonia, [Idescat-2017] and [ECESI-2011]

The six subsectors that are responsible for the largest proportion of energy consumption are (in order of priority for Catalonia): chemical and petrochemical; glass, ceramic and cement; paper and graphic arts; food and tobacco; metal processing; steel and metal. These sectors account for 86.4% of consumption in Europe, 82.9% in Spain and 89.5% in Catalonia. Except for the metal processing sector (outside of Catalonia, the subsector with the lowest useful energy consumption), the other five subsectors manufacture materials, and electrical uses account for only a small fraction; the rest of the energy consumption is for thermal uses.

In Catalonia, the chemical industry consumes the highest proportion of energy (27.5%), followed by the glass, ceramic and cement industry (19.6%). In Spain, the two main, almost equal energy consumers are the chemical and petrochemical industry (20.8%) and the steel and metal industry (19.7%). In Europe, this relationship is inverted: the largest consumer is the steel and metal industry (23.1%) followed by the chemical and petrochemical industry (19.3%).

In recent years, the proportion of energy used in industry in comparison to the rest of the economic sectors has fallen in Europe, Spain and Catalonia in absolute and relative terms. Within industry, energy use in some subsectors has risen, while in others it has dropped.

In Europe between 1990 and 2014, total final consumption increased in industry in the subsectors of paper and graphic arts (+3.9 points) and food and tobacco (+3,3 points), but fell in the steel and metal industry (-4.6 points). In the same period in Spain, total final consumption rose in the glass, ceramic and cement (+4.9 points, including the construction boom) and food and tobacco subsectors (+3,6 points), but fell in the steel and metal subsector (-8,1 points). In Catalonia, in a shorter period (2000-2011, according to a survey [ECESI-2011] by the Catalan Energy Institute [ICAEN]), consumption increased in the chemical and petrochemical (+4.8 points) and food and tobacco subsectors (+4.8 points) and decreased in the glass, ceramic and cement subsector (-6.4 points).

The ECESI survey reveals an aspect that should be highlighted: a small number of companies in Catalonia (and in other geographic areas) absorb most of the total final consumption in the industrial sector (the distribution of useful energy is similar). Out of the 42,580 industrial companies in Catalonia in 2011, a total of 196 companies, each with overall energy use above 29,100 MWh per year (2.5 kTOE/year) used 71.6% of the industrial energy (and 26.9% of the total energy in Catalonia), with an average value of 122,300 MWh per company. Out of these 196 companies, 53 were chemical companies (24.5% of the total industrial energy), 6 cement manufacturers (10.7%), 50 food producers (10.1%) and 19 paper manufacturers (7.7%): in other words, 128 industries in these 4 subsectors used 53.6% of the final industrial energy, and approximately 19.3% of the total useful energy in Catalonia.

Hence, one of the priorities in the energy transition will be to review technological processes in these industries to improve them.

6.1.4 Technical efficiency and suitable uses

In human activities, energy travels along pathways that have two well-defined parts: the first covers the extraction of primary energy up to its conversion into useful energy; the second relates to the consumption of useful energy to obtain the goods and services that people need and want.

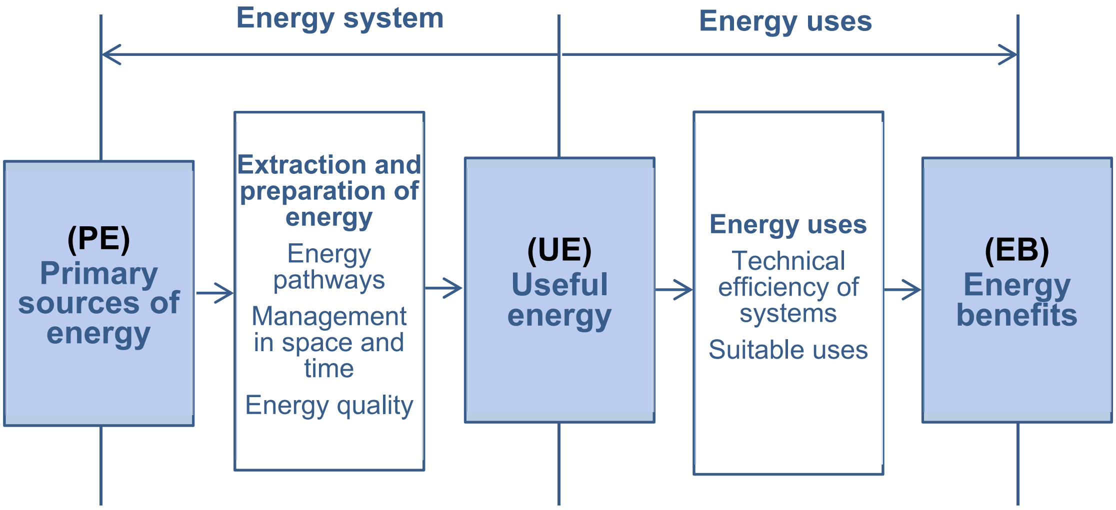


Figure 6.1 Energy system and energy uses

First part of the pathway: energy system

In the current context, a key part of the energy system is in the hands of a powerful energy sector, most of which is comprised of oligopolies that control non-renewable energy sources. This sector takes the first steps in the pathway to generate energy carriers for final energy consumption (commercial fuels and electricity). However, this part of the pathway also includes a considerable proportion of users' processes (particularly in transport) that convert final energy consumption into useful energy. According to data in Table 6.1, at global scale, the energy sector dissipates 32.5% of primary energy, and conversions to useful energy in users' processes dissipate another 27.1%; making a total of 59.6%.

In the future energy system based on distributed, renewable energy sources (solar thermal, photovoltaic, wind, hydraulic and biomass power), in which a substantial proportion of energy will be harvested for own use (or self-consumption) either individually or as a community, new goals such as energy storage must be established, and new business functions defined.

Second part of the pathway: technical efficiency and suitable uses

Migration of the energy system to renewable sources is essential for the energy transition. However, improvement in energy uses through efficiency (the relationship between the resources used and the results achieved) in technological processes, and efficacy (the capacity to produce the desired effect) or suitable uses in human activities could have an impact that is as great or even greater than the switch to renewable energy sources (see the diagram of the energy transition in Figure 6.2).

Therefore, in the area of energy use, there are two additional paths for improvement: *a*) increase the technical efficiency of processes and devices (an aspect that is associated with technical improvements); *b*) promote more suitable uses (a factor that is linked to social behaviour and forms of organisation and management). Frequently, the best results are obtained through a combination of both paths. In developed societies we tend to overlook the fact that improvements in technical efficiency are absorbed by the drift towards increasingly unsuitable uses, unless there is a change in behaviour and in the forms of individual and community organisation. This is known as the rebound effect or the Jevons paradox.

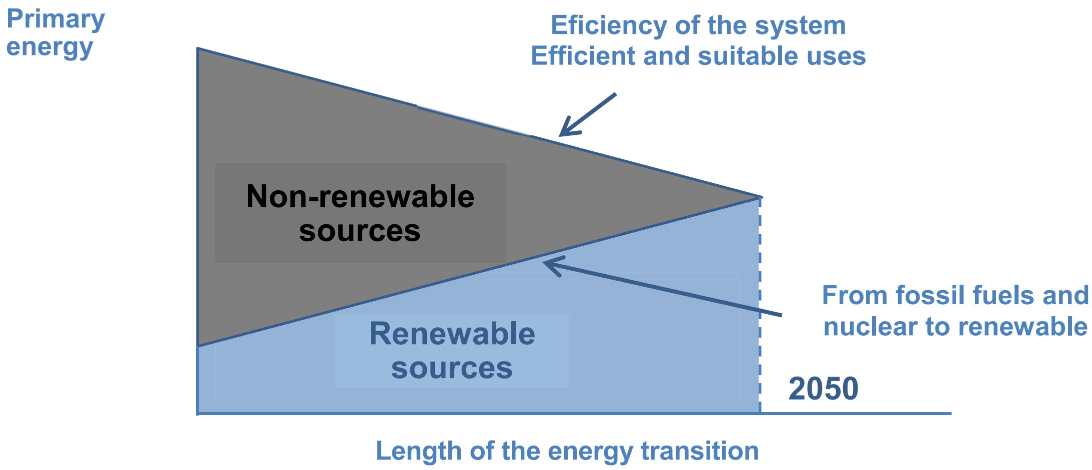


Figure 6.2 Diagram of the evolution towards energy transition

These actions can be illustrated with two examples. In a lighting system, it may be as or more effective to replace incandescent bulbs with energy saving bulbs (greater efficiency) and/or to restrict the use of lighting to when it is necessary (greater efficacy and more suitable uses) as it is to simply supply more electricity, even if it is from renewable sources. In mobility, it may be as or more effective to reduce vehicle resistance by concentrating on its movement or the penetration of air (greater efficiency) and/or to promote the use of public transport in cities (greater efficacy and more suitable uses) as it is to focus on generating more energy to maintain the system, even if it is renewable.

6.1.5 Energy and materials

Product manufacture consists in transforming raw materials into physical products that meet human needs or desires. Manufacture tends to consist of numerous operations, but in many cases (buildings, constructions, machinery, vehicles, domestic electrical appliances and electronic equipment) they can be grouped into two main stages: 1) the manufacture of materials (metals, ceramics, polymers, glass and paper); 2) the shaping and assembly of materials to create the product itself.

Many life cycle assessments indicate that the determining factor is often the energy invested in the materials used in physical objects. For example, the construction of a car requires around 100 GJ of energy (equivalent to 27,800 kWh or 3,100 litres of petrol). Of this energy, approximately 80% is used to obtain materials (steel, aluminium, plastic, rubber and glass) and 20% is consumed in the construction itself. An average dwelling in a developed country requires around 500 GJ of energy (5 times more than a car). In this case, obtaining the materials (cement, ceramics, iron, aluminium, polymers and glass) absorbs over three quarters of the overall energy requirements. The manufacture of electronic material is an even more extreme case, as it may require many times more energy than that consumed during product use.

This coincides with the fact that the sectors of activity that use most energy are those that transform raw materials. It is a priority to review the processes in these sectors. Furthermore, we should consider whether our uses of materials are the most suitable from an energy perspective, or whether we should use other materials or alternative solutions.

Reuse (for example of glass containers) and recycling (particularly of metals, paper and plastic) have a high energy impact. Beyond factors such as scarcity and the environmental impact of waste, many materials required considerable energy to be obtained (embodied energy). In contrast, recycling tends to require much lower amounts of energy (for aluminium, less than 20%; throwing away an aluminium can instead of recycling it means losing the amount of energy that could move a bus 400 metres). Therefore, reuse and recycling make significant energy savings.

We should also examine the current trend of forcing the replacement of products with lower energy alternatives. This solution only considers energy consumption during product use, and artificially shortens product lives, which has the same effect as built-in obsolescence. The energy invested in products also counts, and is particularly important in systems such as electronics.

6.1.6 The time and place for processes

Fossil fuels and uranium are finite and polluting but, as they have high energy density and are stock energy resources, we have become used to establishing human settlements and activities regardless of constraints such as time and place.

Renewable energies are infinite on the human timescale and non-polluting. However, the fact that they are distributed, flowing energy resources means that they are subject to constraints of time and place, as was the case before the Industrial Revolution. It is therefore essential to introduce mass storage systems for electricity and heat that can facilitate energy management that is more similar to that of today. Such systems are of strategic importance.

The storage of energy to use it in the future leads to much greater dissipation than direct use. For electrical energy, storage in batteries and pumped-storage hydroelectricity is quite efficient (between 70% and 80%), but the amount of energy stored and the storage time are limited in relation to the needs of a country's energy system. In contrast, storage through transformation into hydrogen enables much greater amounts of energy to be stored over a much longer time. However, the efficiency of the conversion of electricity to hydrogen and back to electricity is much lower (in the order of 35%), although excess thermal energy can be used (cogeneration).

In the area of energy use, much of the problem can be resolved by two approaches to technological processes: a) locate major energy users in places where they have the best conditions for harvesting renewable energy resources (waterfalls, sunny areas, constant winds, biomass nearby) ; b) adapt the schedule of activities to the online availability of renewable energies. For example, it would be logical for major users of energy to organise their production systems to take advantage of solar energy in the summer, and undertake activities that have lower energy demands during the winter.

This is a field that still needs to be explored. Although the benefits many be great, it has a considerable impact on people's behaviour and forms of organisation. Initially, it is difficult to predict which solutions will be the most effective and produce the best results. The best strategy is probably to progress in all these areas at the same time: storage, location of activities and adaptation of schedules.

6.1.7 Thermal energy in the new renewable system

As shown in points 3 to 5, thermal energy accounts for over half of the useful energy consumed in technological processes in the various fields of activity, and is particularly important in the industrial and residential sectors. In current energy pathways, 92.5% of energy passes through a thermal state, which facilitates thermal uses. However, mobility and a substantial proportion of electricity is obtained mainly from thermal energy through transformations that entail a high level of dissipation (on average worldwide, 66% of energy is lost in electricity production and 80% is lost in combustion engines to propel vehicles).

With the progressive replacement of fossil fuels by renewable sources that are obtained directly in the form of electricity (hydraulic, wind and photovoltaic power), the situation is inverted. In the new energy system, much of the heat required for processes in sectors of activity must be obtained from electricity. Another significant part will come from thermal solar systems (flat-plate collectors and solar thermal collectors) and from sustainable use of biomass.

Uses of thermal energy can be defined according to temperature: *a*) processes that require heat at low temperatures up to 60°C (essentially for heating spaces and domestic hot water, and for washing and cleaning processes); *b*) processes that require heat at medium temperatures of between 60°C and 250 to 300°C (very hot water, steam and thermal oil, normally for industrial processes); *c*) high temperature processes above 250°C (for metalwork, drying of minerals and production of polymers, ceramics and cement, among other uses).

Heat at low temperatures can be obtained: *a*1) directly from solar radiation (flat-plate solar collectors and Trombe walls) with an efficiency above 75% of incident radiation; the energy can be maintained for a certain amount of time in heat accumulators; all of these technologies are low cost, low complexity; *a*2) through a heat pump (for heating, domestic hot water and chilled water): this requires electrical energy, but the thermal energy output can be many times higher (coefficient of performance [COP]: 3 to 6).

Heat at medium temperatures can be obtained from: *b*1) solar thermal collectors (if steam is not required, it is best to use thermal oil to avoid circuits of fluids under pressure); *b*2) specific heat pumps with high COP values; *b*3) combustion of hydrogen or electrical resistance (depending on these resources), with efficiency close to 1; *b*4) a range of specific technologies based on electricity have been developed for heating and cooking foods (resistance, induction and microwave).

Heat at high temperatures can be obtained by: *c*1) heating with electrical resistance or electromagnetic induction (various industrial processes); *c*2) combustion of hydrogen in chambers at very high temperatures: hydrogen is obtained by electrolysis, stored and then burnt, with an efficiency of 65% compared to renewable electricity.

Further efforts must be made in the area of thermal energy: although some technologies are well-known and tested (solar thermal collectors, passive heating and cooling of buildings), other technologies (heat pump, hydrogen as a fuel) have room for significant improvement in their implementation. Biomass is an energy resource that can produce low, medium and high temperatures, but its use is dependent on the need for suitable management of forests and agriculture.

6.2 Responsibilities and oportunities of the UPC

Specialisation in the university environment in recent years has led to a great capacity to analyse and deepen knowledge of specific technological processes. This specialisation has been supported by energy that was abundant and cheap up to now. In many cases, a broader view that considers energy beyond the impact of its costs has been overlooked.

In the context of exhaustion of non-renewable resources and climate change, the perspective of technological processes encourages us to review our knowledge and construct a new, general view that considers what we need to survive.

The Universitat Politècnica de Catalunya and its members have competences in most technological areas, and particularly in the field of energy, through their education and research activities and external collaborations. Therefore, the UPC is in a strong position to promote a new conception of technological processes from the perspective of sustainability and the *transition to a new energy model*.

In general terms, the aim is to consider the cross-cutting environments in which proposals are made (advance research, test new solutions, participate actively in the general debate, and train future generations), and work on the following areas.

6.2.1 Processes of obtaining materials

As has been shown, one of the activities that requires most energy and has the most impact on natural systems is obtaining materials.

In many products, including buildings, infrastructure, durable goods and machinery, much more of the energy that is invested in production (embodied energy) is used to obtain materials (ceramics, metals and polymers) than to transform these materials and make them into products.

The raw materials from which other materials are obtained often need to be extracted through underground or open pit mining. These processes have a profound impact on the territory and the environment – on soil, water and air – but tend to be distant and hidden from much of the population, which is increasingly concentrated in cities.

Probably, one of the most extreme examples is that of electronic systems for information and communication technologies (ICT). The energy requirements for their manufacture tend to be much higher than the energy consumed during their life, and some of the materials (rare earth elements, precious metals, tungsten and tantalum) come from mines in conflict zones.

The primary production of foods is another field that requires attention. Crops capture solar energy, incorporate CO_2 from the atmosphere and matter from the soil, and have an impact on very large areas of land (around 2,200 m^2 per person). The work of farmers, which used to be basically to prepare soil conditions and grow plants for personal benefit, has now been industrialised with the incorporation of artificial inputs that force the natural cycles to increase productivity.

Livestock farming, fishing, aquaculture and forestry (for wood and biomass) have similar characteristics to those of agriculture.

Hence, it is essential to review the processes that lead to the production of raw materials.

6.2.2 New approach to waste and end of life

The model of economic growth, supported by abundant, cheap energy from fossil fuels, has focused on the production of goods and overlooked what happens to the things that we do not want. One of the most conflictive aspects of this situation is what to do with waste and objects that have reached the end of their lives.

Life has been possible on Earth because materials are recycled: oxygen, CO_2, water, nitrogen and other elements. In short, dead organic matter (plants and animals) provides the materials for new living matter. Green plants synthesise new living matter from sunlight and nutrients, and, in turn, provide food for herbivores. Carnivores and omnivores such as man are at the top of this food chain.

The current energy and environmental crisis indicates that the linear economy we have promoted in recent decades (extract, produce and launch) is coming to an end. So much so, that the European Commission has already presented a package of measures on the circular economy and proposed various directives [UE-2015].

The view of technological processes from the perspective of waste and end of life provides a salutary lesson for the *transition to a new energy model*.

6.2.3 Key processes for the new energy model

In various fields of activities, technologies are emerging as key for the *transition to a new energy model*. Some of these technologies are already mature, others are in various stages of development. In any case, before they can be implemented on a large-scale, a phase of social experimentation is needed to ensure they are accepted by part of the population, and to adapt some technical aspects and forms of use.

6.2.4 Transition in technological processes

Based on experience with the introduction of renewable energies in government bodies and companies (particularly industrial companies), the following criteria have been defined for transforming technological processes as part of the *transition to a new energy model*:

- **Criteria 1:** review processes from the perspective of the energy and resources that are used. In most cases, opportunities for substantial improvements can be identified.

- **Criteria 2:** establish synergies between the output and input of processes within organisations or in the surrounding area (for example, in industrial estates) and promote the circular economy. In particular, the opportunities for reuse and recycling need to be studied.

- **Criteria 3:** preferably allocate renewable energy obtained from self-generation to processes in the same organisation or in the surrounding area. In addition to financial savings, this has very positive effects on learning about efficiency and efficacy.

- **Criteria 4:** propose shorter energy pathways (harvest thermal energy for thermal uses and electrical energy for electrical uses), and try to adapt the schedule of activities to the availability of renewable energies.

- **Criteria 5:** consider that the capture of solar thermal energy is much more efficient (from 50 to 70% of incident radiant energy) than photovoltaic power (today, in the order of 15%). Prioritise thermal capture in the many processes that require thermal energy at low or medium temperatures.

- **Criteria 6:** during the period of energy transition, as far as possible, create systems in which the provision of renewable energies is compatible with the use of traditional non-renewable energies that can be used in a complementary fashion.

6.3 Future areas of work of the UPC

A series of future areas of work is proposed that the UPC wishes to, can and must adopt to respond to the challenge of the transition to a new energy model in the area of Technological Processes and Energy:

A. Through **cross-cutting activities** (advance research, test new solutions, participate actively in the general debate and train future generations), the University will work on key aspects such as:

- Promotion of energy and environmental assessment methods for products and processes, particularly through life cycle assessment (LCA).
- Review and optimisation of processes and services, preferably in companies with high energy consumption.
- Creation of new alternatives to improve and optimise current processes.
- Integration of renewable energies into new thermal high-temperature processes.

B. It will also undertake the following **specific actions** in this area:

I. Establish reference lists of materials in different fields with data on the energy required to obtain the materials, their impact on the territory and the environment, how scarce they are and whether there are any social conflicts or geostrategic issues in their place of origin. Use these lists as the basis for more responsible use.

II. From the perspective of energy and environmental impacts, optimise or develop alternatives for processes of obtaining materials (ceramic, cement and glass; steel and metal products; chemical products; paper and others) that are undertaken in the nearest geographic areas (Catalonia, Spain and Europe).

III. Promote an analysis of both waste and large products at the end of their life (organic agricultural and livestock waste, food and hygiene product packaging, healthcare material, waste from catering, domestic electrical appliances, office material and cars) and establish criteria for eliminating them or reducing them at origin. In all cases, reuse them and promote second uses. As a last resort, recycle the materials.

IV. Promote a review of technological processes to minimise the use of energy and other resources, and to adapt the processes to new energy sources. Develop a guide for the transformation of technological processes.

7. Energy system and governance

Contents

7.1 Analysis of the situation and trends

7.1.1 The current system, concentrated in a few hands

The energy system is a set of facilities and processes designed to harvest primary energy from natural sources (fossil fuels, uranium, biomass, solar radiation, wind, water currents and the geothermal gradient) and transform it into useful energy to drive the activities and technological systems that benefit people and communities.

The current energy system is basically comprised of fossil and nuclear fuel extraction and processing plants, power generation plants and distribution facilities, which make up a sector whose aim is to provide final energy in the form of commercial fuels and electricity for all society and its activities. Another part of the energy system is associated with users' processes, such as the conversion of fuel energy into thermal energy for users' activities or into mechanical energy for the mobility of vehicles, or the adaptation of electrical energy (transformers, power lines and power sources) that is required to produce useful energy.

"Governance" is defined as the capacity to make suitable decisions and regulations that consider in a balanced way the needs and interests of the stakeholders in the energy system (suppliers and users).

Today, almost 90% of the primary energy resources obtained and transformed in the world (fossil fuels, uranium and hydroelectric resources) are channelled through an energy sector formed by large oligopolistic corporations (coal, oil, gas, nuclear and hydroelectric companies and related industries). The remaining 10% is managed in a more distributed way and includes: waste and biomass, particularly in developing countries in Sub-Saharan Africa and South-East Asia, and a considerable proportion of the new sources of renewable electrical energy (solar thermal, photovoltaic and wind power).

This situation has meant that, in many cases, the large oligopolistic corporations have controlled the governance of the energy system, to the detriment of users and small electricity generators. Government bodies have been ill-prepared, with little knowledge of the generation and distribution of energy. Their actions and regulation of the industry have been weak, and they have on occasions been influenced by the interests of the oligopoly.

7.1.2 Losses in the energy system

The conversion of primary energy (PE) into useful energy (UE) passes through two stages in which the current system experiences very great losses, mainly due to the thermodynamic processes that are involved. The first stage is the step from primary energy (PE) to final energy (FE, commercial fuels and electricity) that takes place in the heart of the energy sector. The second stage is the step from final energy (FE) to useful energy (UE), which takes place in users' processes. Below is an overall analysis of losses in relation to different geographic areas.

Losses in the energy sector

The energy balances of the International Energy Agency (IEA, part of the OECD) only consider the first part of the energy pathway, up to final energy (which is known as total final consumption [TFC] in IEA energy balances). This corresponds to the activity of the energy sector (mainly controlled by large, oligopolistic companies) that obtain primary resources from nature, transform them, and distribute them in the form of energy carriers (commercial fuels and electricity) to the various users.

In 2014, the amount of energy dissipated between primary energy (excluding non-energy uses) and final energy when it leaves the energy sector, by geographic region, was:

32.5% in the world (almost a third)
31.7% in OECD countries
33.0% in non-OECD countries
29.9% in the EU28
29.2% in Spain
and 34.2% in Catalonia.

Most energy is dissipated when electricity is obtained from thermal sources (coal, natural gas, nuclear and biomass): on average, only one out of every three units of thermal energy is transformed into electricity. In the extraction and transformation of fuels, this ratio is around 85%. Globally, dissipation in the energy sector has increased over 3 points since 1990, largely due to the increase in electrification, particularly in non-OECD countries. In OECD countries it has decreased slightly due to better techniques (cogeneration and combined-cycle power plants).

In the global energy sector, the process of extracting, transforming and distributing fossil fuels up to the generation of final energy (commercial fuels and electricity) emits 50% of the 32,380 million tonnes of CO_2 per year that are emitted when these resources are used.

Losses in user processes

It could be considered that the energy carriers in final energy (commercial fuels, electricity) directly provide the energy required for human activities. However, this is not the case, as we can see in the first steps of the energy transition. For example, in the replacement of a vehicle with a combustion engine by an electric vehicle: in the first vehicle, only 25% on average of the energy content of fuels (final energy) is transformed into useful energy for the activity of transport (to move wheels, propeller or jet). The rest is dissipated in exhaust gases. In contrast, in a battery-powered electric vehicle, 70% of the electrical energy from the grid is transformed into mechanical energy to move the wheels.

Globally (2014), the additional dissipation of non-useful energy in user processes in relation to primary energy by geographic area is:

27.1% in the world
29.8% in OECD countries
25.3% in non-OECD countries
29.3% In the EU28
33.4% in Spain
and 32.2% in Catalonia.

Above all, these percentages reflect the importance of transport in the respective economies.

Inefficiency in the current energy system

Pathways in the current energy system, based largely on inefficient thermodynamic transformations, accumulate inefficiencies in the energy sector's processes of extraction, transformation and distribution, and inefficiencies caused by energy-to-energy transformations in user processes that are not useful for the final objectives.

In 2014, figures for accumulated energy dissipation in pathways from primary energy to useful energy by geographic region were:

59.6% in the world (only 40.4% of primary energy is transformed into useful energy)
61.5% in OECD countries
58.3% in non-OECD countries
59.2% in the EU28
62.6% in Spain
and 66.4% in Catalonia.

Inefficiency has gone up over time (in 1990 at global scale, it was 56.8%, 2.8 points less than in 2014), mainly due to an increase in the importance of transport, which is the most inefficient sector in relation to final uses.

Table 7.1 summarises the data given in the above sections:

Table 7.1 Losses (in %) between primary energy (PE) and useful energy (UE)

Losses %PE	World	OECD	Non-OECD	EU28	Spain	Catalonia
Energy sector (PE to FE) [1]	32,5 %	31,7 %	33,0 %	29,9 %	29,2 %	34,2 %
User processes (FE a UE) [2]	27,1 %	29,8 %	25,3 %	29,3 %	33,4 %	32,2 %
Total (sum of the above)	59,6 %	61,5 %	58,3 %	59,2 %	62,6 %	66,4 %

[1] Losses between primary energy (PE) and final energy (FE) as a percentage of primary energy.
[2] Losses between final energy (FE) and useful energy (UE) as a percentage of primary energy.
Sources: [IEA-2017], [Idescat-2017]

7.1.3 From combustion to electricity generation

According to IEA data for 2014 and excluding fossil fuels used in non-energy applications (such as polymers and fertilisers), 95.9% of primary energy in the world (fossil fuels, 79.6%; nuclear energy, 5.2%; and biomass, 11.1%) is used in thermal processes (thermo-mechanical processes for mobility, thermo-mechanical-electrical processes to produce electricity, or to produce heat). Only the remaining 4.1% of primary energy is generated directly as electricity without passing through a thermal phase (hydroelectrical energy, 2.6%; and new renewable sources, 1.4%). In the IEA energy balances, electrical renewable energies (measured in electricity) are much lower than the rest of energy sources (measured in potential heat).

However, an analysis of useful energy requirements (the energy that drives processes and devices, based on today's needs) shows the following distribution: 60.4% for thermal uses, 13.5% for mobility (including the small fraction of electricity used in electric traction), and the remaining 26.1% for electrical uses (some of which are transformed into thermal uses: stoves, ovens, heating and electric heaters, as well as some industrial processes). In any case, the growing importance of electrical uses is clearly demonstrated.

In the new system, sources that generate electricity (hydroelectric, wind, photovoltaic and marine power) will predominate, while the main thermal energy sources today (fossil fuels and nuclear energy) must be reduced drastically until they reach zero. Therefore, we will shift from a system with an excess of thermal sources that largely have to be converted to electricity and mobility, to a system with a greater abundance of electrical sources that largely have to be converted to mobility and heat.

Mobility, 97.6% of which is currently based on thermal sources (91.4% derived from crude oil), must move towards electrical sources. Many of the low-temperature thermal uses in the domestic, industrial and service sectors (air conditioning and heating of buildings, domestic hot water, cooking and low-temperature industrial processes) will also have to shift from fossil fuels to solar thermal energy, electrical devices and heat pumps. Heat pumps have high performance, but also consume electrical energy.

7.1.4 From stock to flow energy sources

From the perspective of availability, the forms of energy resources can be distributed into three main categories:

a) Stock resources, which are widely available in terms of power and time. However, although they are not yet exhausted, they are finite and non-renewable (fossil fuels and uranium).

b) Flow resources, which are intermittent and/or random and cannot be stored. They are not very concentrated in terms of the territory in which they are harvested, but cannot be exhausted on a human timescale and are therefore renewable (photovoltaic, wind, wave, water current or tidal power).

c) Flow-stock energy resources, which have similar characteristics to flow energy resources, but can be stored in limited amounts for short times (biomass, hydroelectric and solar thermal power). Geothermal energy is based on an almost constant flow. Hydrogen is a future energy carrier that can convert flow energy into stock.

Stock energy resources (fossil fuels and uranium, 84.7% of the total energy mix), complemented by flow-stock energies that can be stored (hydroelectricity and biomass, 13.7% of the total), have shaped the current energy system. They are available when required depending on the energy demand. In the new renewable energy system, in which fossil fuels and uranium are in decline, energy that can be stored will move from a leading position to a supporting role, and the energy paradigm will shift.

The issue of availability of stock energy should be resolved through two complementary strategies: 1) the development of systems to store energy in large quantities that endure over time, particularly electricity and hydrogen as an energy carrier that can be transformed into thermal energy, electricity or a combination of both, according to needs; 2) the adaptation in space and time of energy uses to the availability provided by renewable sources, the geographic location of major energy users close to the main sources of energy, and the adaptation of schedules to the availability of renewable sources.

7.1.5 Energy storage: a strategic factor

Today, fossil fuels (stock energies) provide energy services (electricity, mobility and heat) at any level of power (from 1 W to 1 GW) at any time (day and night, summer and winter). However, their progressive decline, increasing costs and environmental impacts are no longer acceptable. Hence, the storage of energy, and particularly electrical energy, is a strategic factor in the new renewable energy system.

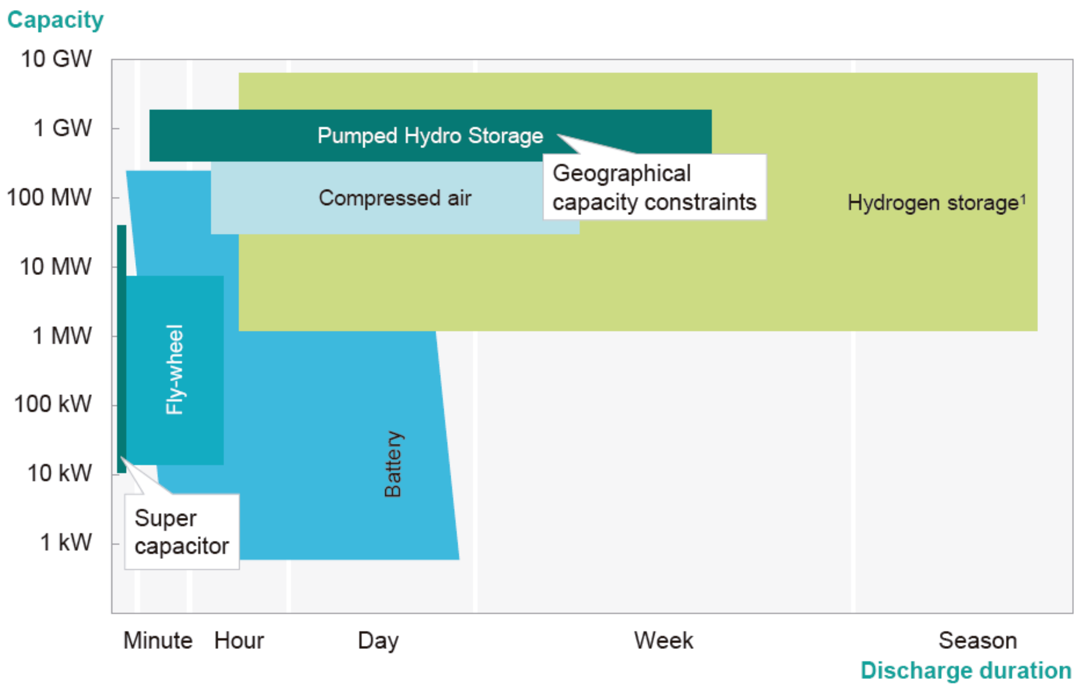


Figure 7.1 Fields of application of energy storage systems by amount of energy and storae time [Hydrogen Council-2017]

Today, the basic forms of energy storage are:

a) *Thermal collectors*, with no energy transformation, available in a wide range of designs and dimensions, but with a limited capacity for energy storage over time: from hours to a few days.

b) *Electric batteries*, which transform electricity into chemical energy and back to electricity with high overall efficiency (between 75 and 85%). They are easily scalable and can be used to power objects from micro-devices to cars. However, they discharge over time, are expensive and are not highly sustainable. They have low energy storage capacity in relation to all of society’s electricity system requirements.

c) *Pumped-storage power plants*, with two reservoirs, transform electricity into hydraulic energy and back to electricity with high overall efficiency (in the order of 80%). They have high transformation power that is suitable for occasional regulation of the electricity system. However, their storage capacity is limited in relation to society's electricity system requirements in the long term.

d) *Hydrogen*, which is obtained from the decomposition of water via electrolysis and for which massive storage systems are being developed. The main energy uses of hydrogen are: in vehicles, transformation into electricity (fuel cells) and electric traction; in the electricity grid, to meet needs in periods in which renewable energy sources are insufficient (fuel cells or replacement of natural gas in combined cycle power stations); in industry, to fuel high-temperature combustion chambers. The overall efficiency of the conversion of electricity to hydrogen and back to electricity is approximately 35%; and that of the conversion of electricity to hydrogen followed by high-temperature combustion is around 70%.

   The possibility of converting hydrogen into other liquid or gas fuels that do not emit greenhouse gases is also being studied.

Research and the development of energy storage systems is vital to complete the energy transition. Mass storage systems (in which hydrogen could become a key technology) will be of strategic importance when the penetration of renewable energy sources in the global energy system (for electricity, traction and thermal uses) reaches a certain threshold, which could be situated between 30% and 40%.

7.1.6 Distribution, scalability and participation

Another aspect that has great transformative potential in the new renewable energy system is the territorial distribution of energy sources (solar radiation, wind, water currents, low enthalpy geothermal resources and biomass) and the scalability of facilities to obtain energy. In most cases, energy harvesting facilities could range from very small (at the scale of the device or dwelling) to facilities comparable to medium-sized electric power stations today.

Scalability in the process of obtaining energy in the new renewable energy system, combined with the new capacity for digital control and management of uses (the internet of things, IoT), could lead to greater efficacy in the direct allocation of generation capacities and energy use requirements, particularly with respect to electrical energy at small territorial scales.

The aforementioned factors (territorial distribution and scalability), particularly with respect to energy harvesting, are factors that facilitate progress towards energy sovereignty and the energy supply of a society that is more participative, democratic and egalitarian in energy terms and in its overall organisation.

7.1.7 Useful energy and the new energy model

Useful energy is what really drives technological processes and moves objects, excluding the energy dissipated in transformations that do not contribute directly to uses. Useful energy is therefore what provides the desired effects (food, heating, lighting, mobility, information, communication, materials, products and services). In the case of uses outside the energy system, system efficacy is an important concept, that is, the relation between the goods that are obtained and the resources used, including energy.

Therefore, the new energy system based on renewable sources must make useful energy a point of reference. In all foresight exercises carried out for a system based on 100% renewable sources, a smaller amount of primary energy is required to provide the same energy services (or useful energy). This is due mainly to greater efficiency in electrical transformations in comparison with the thermodynamic processes that are based on fuels.

At the same time, new questions should be asked in the *transition to a new energy model*: which renewable energy sources are most suitable for each environment? Which are the most appropriate energy pathways? How will the system be governed and how will the population participate in and control it? In terms of space, do we need to advance towards a distributed system or simply a decentralised one? In terms of time, do we need to adapt energy uses to natural rhythms as far as possible, or continue to carry out our activities without taking these rhythms into account?

The shift from an economic and social system based on fossil fuels and uranium to a new system based on renewable energies involves some key changes in the physical configuration of human settlements (uses of the territory, the metabolism of cities, and infrastructure) and in the forms of human behaviour and social organisation.

This transformation cannot be undertaken suddenly. It requires a process in which the old system based on fossil and nuclear fuel is gradually replaced with the new system based on renewable energy sources. Many studies and authoritative voices on the exhaustion of non-renewable energy resources and the need to limit the effects of climate change indicate that the energy transition should be completed before 2050.

Therefore, we should not only design the new renewable system, but also establish forms of temporary coexistence and compatibility between the new system and the old. Many elements in the new system must be implemented gradually to ensure that the old system can complement the new system and meet energy needs that still do not have an alternative.

At the same time, it is essential to have a clear idea of the final objective of the energy transition, to avoid taking the wrong steps or encountering setbacks in the process. This final objective is to introduce a renewable energy system that is compatible with life and open to a new social economy that is more democratically distributed and fair.

7.2 Responsibilities and opportunities of the UPC

The knowledge and the teaching, research and external collaboration activities of members of the Universitat Politècnica de Catalunya are closely associated with the configuration of the future energy system and its system of governance.

As a public entity, the Universitat Politècnica de Catalunya must participate actively in this transformation through teaching, research and collaboration with society. In turn, it provides opportunities for activities and self-funding.

In general terms, the cross-cutting actions that we propose are focused on the areas of advancing research, testing new solutions in the university community, actively participating in the general debate, and training future generations.

7.2.1 Training for the energy transition

One of the missions of universities in general, and of the Universitat Politècnica de Catalunya in particular, is to analyse critical situations that arise and warn the public and political leaders. The fossil fuel and nuclear energy crisis is one of these situations. In fact, it is probably the most relevant situation in the early twenty-first century.

To introduce the new renewable energy system, we must construct a new global, holistic approach based on our material foundations, our ways of thinking and our political and social organisation. The transition to a new energy model will lead to complex, conflictive situations in which the old and new system clash, and situations of temporary coexistence must be resolved.

Consequently, we must make a great effort to come together and pool resources. Specialisations must give way to integrated views that take all aspects into account. The process of meeting and debate at the UPC, which led to this document, is just one step. The Universitat Politècnica de Catalunya must extend this process of group reflection in two directions: *a*) to all its students; *b*) to all society, particularly those responsible for social, business and political organisations.

7.2.2 Studies on new energy requirements

Energy consumption in Catalonia in 2014 (excluding hydrocarbons for non-energy uses) stood at 264 TWh (in 2000, the figure was 255 TWh; in 2009, it was 286 TWh).

Out of the primary energy, 43.3% is from oil, 26.4% from nuclear energy and 22.0% from natural gas; the amount of coal is negligible (0,1%). A total of 6.3% of primary energy is from renewable sources (one of the lowest proportions in Europe): 2.8% from biomass and waste, 2.1% hydroelectric power, and 1.4% wind and photovoltaic power. The remaining 1.9% is comprised of imported electricity.

Table 7.2 Catalonia: a comparison between primary, final and useful energy

Catalonia 2014	Primary energy		Final energy		Useful energy	
	TWh	%	TWh	%	TWh	%
	264,2	100,0 %	174,0	100,0 %	88,9	100,0 %
Residential	41,3	15,6 %	22,9	13,1 %	18,1	20,3 %
Transport	101,0	38,2 %	86,8	49,9 %	22,1	24,8 %
Industry	72,8	27,5 %	41,2	23,7 %	32,6	36,7 %
Services (exc. transport)	43,1	16,3 %	18,4	10,6 %	14,7	16,5 %
Others	6,0	2,3 %	4,8	2,7 %	1,5	1,6 %

Source: Idescat

The new sustainable energy system must refer to useful energy; the energy that really drives processes and devices. A high proportion of useful energy is consumed by industry, whereas the proportion for transport is much lower. In addition, the effects of energy savings must be taken into account.

There is still a long way to go in the *transition to a new energy model*.

One first step is to analyse energy uses by sector of activity (residential, mobility, primary sectors, industry, construction and services), in terms of qualitative and quantitative factors and trends.

The Catalan Energy Institute (ICAEN) has taken a first step in this direction with its report Statistics on Energy Consumption in the Industrial Sector (ECESI), whose analysis is of great interest to identify energy uses in industrial subsectors. However, further analyses like this should be undertaken and extended to other activities.

There is a tendency to focus on major technological innovations, particularly those associated with information and communication. Nevertheless, we should not forget that these require high quality energy, without which they cannot function.

7.2.3 A new relationship between energy and territory

Unlike the fossil and nuclear energy system, energy harvesting in the renewable system is undertaken on the surface of the territory.

The harvesting of direct solar radiation requires large areas of flat-plate solar collectors, solar thermal collectors and photovoltaic panels. A similar situation is found with other renewable sources: hydroelectric energy makes use of the rainwater in an entire basin; biomass is the result of the conversion of solar radiation by plants in large areas of forests and croplands; wind energy takes advantage of air movements produced in distant places, but wind generators need to be distributed over the land (or sea) so that they do not cast shadows on each other. Low enthalpy geothermal resources are also distributed over the surface of the earth. Only high temperature geothermal sites do not follow this pattern, but there are very few of them.

Therefore, energy generation must be added to the many existing functions of land, particularly its ecological, agricultural and urban functions. This requires a radical reconsideration of all land use planning.

Initial assessments of surface area requirements for energy harvesting in Catalonia give figures of between 40,000 and 66,000 hectares (1.25 to 2.05% of Catalonia). For comparative purposes, the surface area of Catalonia that has been developed is 215,000 hectares (6.7% of the territory) and the surface area for agriculture is around 780,000 hectares (24.3%).

Catalonia has very uneven distributions of settlements and activities over the territory. For example, the Barcelona Metropolitan Area has 3.21 million inhabitants (43% of the Catalan population) and occupies 635 km^2 (2.0% of the territory of Catalonia). Consequently, imaginative solutions must be found, and commitments made between different parts of the territory.

The energy transition to renewable sources will lead to a radical change in social organisation with respect to the territory. This fact has not yet been assumed by the general public or by those responsible for government. Therefore, the Universitat Politècnica de Catalunya must work to ensure that the general public and political leaders become aware of the association between territory and energy.

7.2.4 Research on resource and energy savings

In the last decades before the 2008 recession, energy supply increased leading to great advances in living conditions worldwide, particularly in developed and emerging countries. Since the 1960s, fossil fuels have accounted for around 80% of the energy mix in this supply.

Due to the abundance and low cost of energy, people have not been concerned about the origin of resources and energy, the health of natural systems, and the Earth's limits.

The problems that have emerged in recent years, including difficulties in accessing energy or energy poverty and increasing energy costs, are perceived as an economic issue relating to social inequality (which it also is). There is no general awareness of the limits of the current energy model, associated with the threat of exhaustion of non-renewable resources and the environmental impacts of fossil fuels.

In this context, we cannot focus only on replacing non-renewable energies with renewable energies: we must also review the trend of using energy and resources indiscriminately in increasing amounts. The efforts made to promote renewable energy sources could be absorbed by an unconcerned increase in energy uses (as in the Jevons paradox). Consequently, it is essential to review current technological processes and energy uses in depth. This could lead to savings of around 40% or more of the primary energy resources that we consume today, without reducing quality of life.

The Universitat Politècnica de Catalunya has the capabilities and is in an excellent position to review technological processes. The establishment of an agreement on this matter with the Government of Catalonia and other government bodies will help to take a vital step in *the transition to a new energy model*. The UPC can become a benchmark and a stimulus for all society.

7.2.5 Research on renewable energies

Today, renewable sources of energy are the only viable alternative, and are the direction that the new energy model must take. Even if nuclear fusion were successful, its full implementation would be achieved long after the crisis of fossil fuels and uranium (finite, polluting and hazardous) had reached the point of no return.

Therefore, it is essential to promote basic and applied research into renewable energies, and the Universitat Politècnica de Catalunya is in the best position to do this in Catalonia.

An analysis of resources that have energy potential in Catalonia highlighted: solar radiation, wind, hydraulic resources, biomass and low-temperature geothermal resources.

Water resources share essential functions and uses, including ecological flows, agricultural irrigation, drinking water, sanitary water and water for industry. The management of water to generate energy should be secondary to these priorities. Hydraulic energy plays a role in Catalonia, but it would not be easy to expand this role. Similarly, biomass shares other crucial functions, such as biodiversity, oxygen turnover, soil preservation and rainwater retention. Agriculture should be primarily focused on food, and agricultural waste is a cheap, environmentally friendly way to fertilise the land. Biomass for energy must be secondary to these functions.

Winds, particularly constant laminar winds, are more predominant in northern Europe. In contrast, Catalonia enjoys a high number of sunshine hours in the entire territory.

There are a certain number of low-temperature geothermal energy (<60°C) sites in Catalonia, particularly in places that have the word “Caldes” in their name. These could provide local hot water or heating solutions. Soils, as low enthalpy geothermal resources, could provide good solutions in combination with heat pumps.

In principle, no source of energy should be underestimated. The Universitat Politècnica de Catalunya must remain open to all possibilities. Many of the scattered sources of energy could be useful at local scale (for example, forestry biomass or gasification of animal slurry or other organic waste).

Therefore, projects that are strongly linked to the resources offered in each place and time (day-night, different seasons, etc.) should be promoted.

7.2.6 Research on energy storage

Most of the new renewable energies are intermittent (solar energy) or random (wind and rain) flows that are not available for use in the same way as fossil fuels, which can be burnt when required by demand. In addition, many renewable resources generate electricity (hydroelectric, wind and photovoltaic power) that must be used the moment it is produced.

The new renewable energy system will require strategies to match demand to energy generation, and to develop energy storage systems on a large scale.

As the energy transition advances and the proportion of intermittent and/or random renewable energies increases, the association between energy generation and demand (beyond 30% or 40%) will be increasingly difficult. Therefore, energy storage (particularly of electricity) is essential to progress.

In the final stages of the transition when renewable resources provide most of the energy, we will need massive, durable forms of storage distributed throughout society. Today, the system that seems to best meet these requirements is hydrogen storage. Flow and stock energies provide a certain amount of storage (pumped-storage hydroelectricity, biomass and biofuels) and can provide stability and security that is of immense importance in the future energy system.

7.2.7 Research on network management

A new, distributed renewable energy system in which there are many generators and users ranging from very small to very large, with traditional functions (a secure supply and energy quality) and new functions such as storage, will also require a new regulatory system based on new concepts.

A new pricing system must take into account three aspects: a) a secure supply and the investments that make this possible; b) the promotion of energy saving; c) the promotion of energy use close to the place and time at which it is harvested, to avoid storage.

7.2.8 The UPC: a platform for pilot schemes

The Universitat Politècnica de Catalunya is a large organisation (3,000 lecturers and researchers, 1,800 administrative and service staff and 32,200 students) distributed over 9 campuses (three in Barcelona, and in Castelldefels, Igualada, Manresa, Sant Cugat del Vallès, Terrassa and Vilanova i la Geltrú), with 18 schools and faculties.

Universitat Politècnica de Catalunya facilities include a high number of buildings (over 60) with air conditioning and heating systems and numerous classrooms and laboratories of different types (for studies of electricity, chemistry, materials, crops, processes, etc.). It houses many bars and restaurants, and is the reason for a large number of journeys from the homes of students and workers to the campuses.

This set of activities and circumstances create a microcosm that can become the site of various pilot schemes. Proximity and the University's capacity for observation, analysis, evaluation and experimentation make this an ideal place for testing ideas.

7.3 Future areas of work of the UPC

A series of future areas of work is proposed that the UPC wishes to, can and must adopt to respond to the challenge of the transition to a new energy model in the area of Energy System and Governance.

A. Through **cross-cutting activities** (advance research, test new solutions, participate actively in the general debate and train future generations), the University will work on key aspects such as:
   - The development of criteria for the energy transition relating to technologies, social behaviour, scheduling and location.
   - Energy uses in the primary sectors.
   - The development of technologies and experimentation on energy storage for future scenarios.
   - The development of land planning criteria, based on the surface area required for the future renewable energy system (land use priorities, assessment of areas to preserve, etc.).

B. It will also undertake the following **specific actions** in this area:

I. Develop and maintain tools to identify and assess energy uses in the primary sectors (agriculture, livestock farming, fishing, aquaculture, forestry, etc.).
II. Develop tools to identify and assess energy use in the residential sector for air conditioning, heating and domestic hot water; preservation and preparation of food; cleaning; and activities relating to information and communication.
III. Develop and maintain tools to identify energy uses in passenger and goods mobility by land (road and rail), air and sea.
IV. Support the continuity and improvement of the ECESI survey by ICAEN to advance knowledge and assessment of energy uses in industry.
V. Focus research on solar thermal, photovoltaic, wind, hydraulic and geothermal energy, with an integrated vision of a new renewable energy system.
VI. Analyse, study and propose models for regulatory and pricing systems associated with the new renewable, distributed energy system.

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