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CHAPTER 1

ENERGY, ENVIRONMENT AND ECOSYTEM RELATIONS

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Abstract: Ecology is as old as the existence of mankind in a sense, and one of the newest branches of science in another sense. In this part of the book some basic concepts of ecology, what parts of the ecosystems are made up will be discussed in detail. We will look at how these pieces came together in the ecosystem. Ecology, scope of ecology, ecological networks, energy flow and nutrient flows will be presented. The concept of food chain and energy flow in ecosystems and materials cycle in the biosphere, food web and food chain and the effect of human involvement on biospheres' cycling will be examined. At the end of this chapter, contaminant's fate and transport in the ecosystem will be presented.

Learning objectives:

At the end of this chapter, the student will be able to:

- Describe the ecology term,
- Define the components of ecosystem,
- Discuss the scopes of ecology,
- Compare the structure that contains both the abiotic and biotic composition,
- Discuss the networks present in the ecological system has a control of the energy flow and also in the flow of nutrients,
- Be aware that energy from our solar system has a control over the flow of all the nutrient and energy,
- Explain the concept of food chain and energy flow in ecosystems,
- Explain how materials cycle in the biosphere,
- Distinguish between food chain and food web,
- Explain the effect of human involvement on biospheres' cycling.

1.1 Ecology as a course

Ecology is part of biology by dealing with life, organism and population. It is a multidisciplinary science that uses the tools of other disciplines to explain natural observed phenomena.

The word 'Ecology' was coined from the Greek World 'oikos' meaning 'house' or 'a place to live' to designate the study of organisms in their natural homes. Specially, it means the study of interactions of organisms with one another and with the physical and chemical environment. The term "logy" is to mean study (Ambelu et al., 2007).

1.2 Ecological terms

Biomes: A large, relatively distinct terrestrial region characterized by a similar climate, soil, plants, and animals regardless of where it occurs on earth.

Tundra: It is the most of the world's landmasses. Dominant vegetation is moss, grass and some small perennials.

Taiga: The deciduous forest having a great diversity of mammals, birds, and insects as well as modest number of reptiles and amphibians.

Grassland: An area where annual rainfall is not sufficient to sustain the growth of trees.

Desert: An area, which is receiving less than 10 inch of rainfall per year. Lack of moisture is the essential factor that shapes the desert biome.

Tropical rain forest: It is characterized by high temperature, high annual rainfall and by a great variety of plants and animal species.

Aquatic Biomes: Estuaries are enclosed body of water where saltwater from the sea mixes with freshwater from **rivers, streams and creeks.** Besides being the most biologically productive ecosystems on the planet, they also act as filters for pollutants and protect from flooding.

Habitat: The habitat of an organism is the place where it lives, a physical and it may be as large as the ocean or a forest or as small and restricted.

Ecologic Niche: Every organism has its own role within the structure and function of a community. This status or role of organism in the community or ecosystem is termed as ecologic niche. It is helpful to consider the habitat as an organism's address (where it lives) and the ecologic niche as its profession (what it does biologically).

Food chain: Linear sequence of who eats whom in an ecosystem.

Biogeochemical cycle: The cycling of materials through living system and back to the earth.

Eutrophication: A process by which a body of water becomes over- enriched with nutrients, and as a result produces an over- abundance of plants.

Biomass: The total dry mass of all living organisms at a given tropic level of an ecosystem.

Community: the population of all species that occupy a habitat.

Tropic level: All organisms that are the same number of energy transfer away from the original source of (e.g. sun light) that enters an ecosystem.

Ecosystem: A community and its physical and chemical environment. An ecosystem has a living (biotic) and nonliving (a biotic) component.

1.3 Components of ecosystem

Non-living components of an ecosystem: The non-living or abiotic parts of ecosystems have both physical (wind, terrain, soil moisture, water current, temperature, soil porosity etc.) and chemical features (water, gases, minerals, other complex chemicals).

Living component of an ecosystem: Living organisms.

Producers: All green plants are producers: they assimilate simple chemicals from the soil, water and air, with the help of energy from the sun, transforms them by **photosynthesis** into more complex energy-rich chemicals that eventually make up the plant there by producing oxygen.

$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$………………. Eqn (1.1)

Except for chemotrophs, all living things other than green plants are consumers. They consume chemical energy and nutrients derived from other living things.

Consumers: Cows eat plants and therefore they are called herbivores. They can also be called vegetarians. Because they get their food directly from producers strict herbivores are also called primary consumers. Organisms that eat plant eaters are called secondary consumers, since their food is one step moved from plants. They are also called carnivores. Thus, an animal that eats a secondary consumer is called a tertiary consumer, and so on.

Decomposers: Decomposers are consumers that get energy and nutrients by digesting waste matter and dead plant or animal material. Decomposers are the organisms mostly bacteria and fungi-responsible for decay, decomposition, or rotting. They are responsible for the completion of ecosystem mineral cycles.

Nitrification: A process by which certain soil bacteria strip ammonia or ammonium of electrons, and nitrite (NO_2) is released as a reaction product, then other soil bacteria use nitrite for energy metabolism, yielding nitrate (NO_3^-).

Ammonification: Decomposition of nitrogenous wastes and remains of organisms by certain bacteria and fungi.

Denitrification: Reduction of nitrate or nitrite to gaseous nitrogen (N_2) and a small amount of nitrous oxide (NO_2) by soil bacteria.

Nitrogen fixation: Among some bacteria, assimilation of gaseous nitrogen (N_2) from the air; though reduction reactions, electrons become attached to the nitrogen, there by forming ammonia (NH_3) or ammonium (NH_4^+).

Ecosystems are open systems and hence require continuous energy and nutrient inputs. The functioning of an ecosystem involves a series of cycles, like water cycle, nutrient cycle, etc.

Trophic organization: Ecosystems have a layered structure based on the number of times energy is transferred from one organism to another, away from the initial energy input into the system. Thus, all organisms that are in the same number of transfer steps away from the energy input are said to be at the same trophic level. The transfer of food energy from plants to animals and then to other animals by successive stages of feeding (trophic level) is termed as food chain.

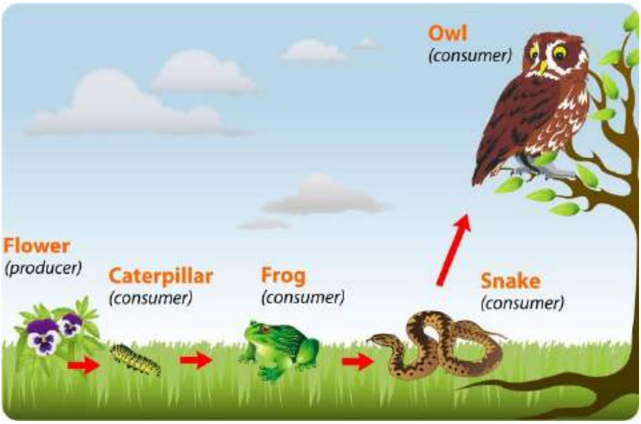

Figure 1.1. Example of food chain (https://www.google.com.tr/search?q=food+chain)

At each transfer, in a food chain (see Figure 1.1), a large portion of potential energy present in the chemical bonds of the food is lost as heat. Because of this progressive loss of energy (in the food process) as heat, the total energy flow at each succeeding level is less and less. This limits the number of steps in a food chain, usually, to four or five.

In most cases the relationships between the organisms involved are so complex that the chain is in the form of a highly complicated and branching network called food web (see Figure 1.2), which is actually the existing feeding relationship in an ecosystem.

An ecosystem also can be represented by ecological pyramids. There are three general types of pyramids (see Figure 1.3).

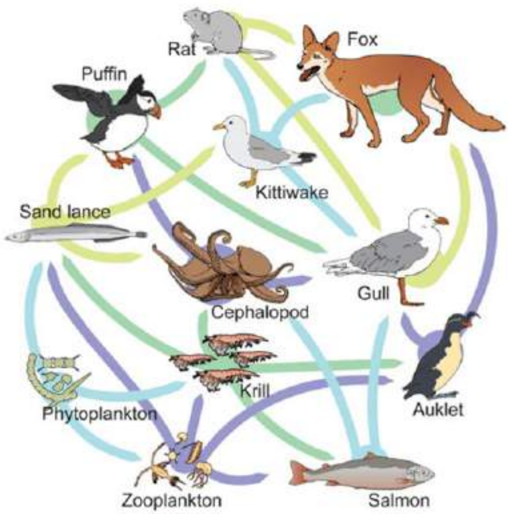

Figure 1.2. Example of food web (https://www.google.com.tr/search?q=food+web)

Pyramid of numbers: This pyramid is constructed by counting the number of individuals involved in each trophic level.

a) **Pyramid of biomass:** Pyramid of biomass is constructed by measuring the weight of dry living matter in each trophic level.
b) **Pyramid of energy:** This is made by measuring the energy content of organisms at each trophic level.

c) **Pyramid of productivity:** Productivity pyramids show the flow of energy through the food chain.

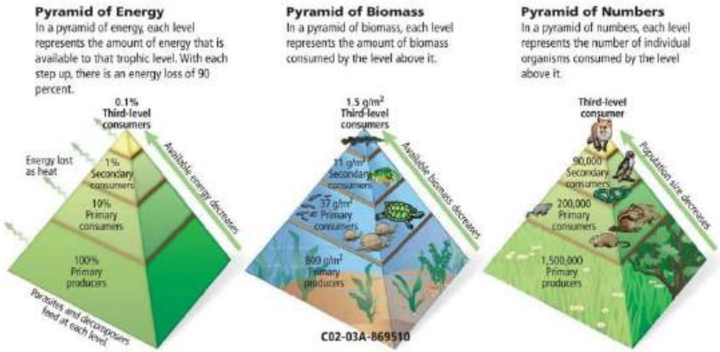

Figure 1.3. Ecological pyramids (https://www.google.com.tr/search?q=food+web)

When energy is transferred to the next trophic level, only 10% of it is used to build new biomass and the rest going to metabolic processes (10 % rule).

Function of ecosystem: The function of an ecosystem is related to energy flow and material cycling through and within the ecosystem.

Energy flow: Ultimately, most organisms depend on the sun for the energy needed to create structures and carry out life process. The transfer of energy through an ecosystem begins when the energy of sunlight is fixed in a green plant by photosynthesis. At each transfer of energy with in a food chain, approximately 90% of the chemical energy stored in the lower level is lost, and therefore unavailable to the higher level. Since the total amount of energy entering the food chain is fixed by photosynthetic activates of plants, more usable energy is available to organisms occupying lower position in the food chain than to those at higher tropic level. Expressing this concept in simpler terms, one might say for example: Corn-Beef-Human; 10000 units of energy 1000 of energy units 100 units of energy.

By moving man one step lower in the food chain, ten times more energy becomes directly available. Corn – Beef; 1000 units of energy 1000 units of energy.

1.4 Biogeochemical cycling

All living organisms are dependent not only on a source of energy, but also on a number of inorganic materials, which are continuously being circulated throughout the ecosystem. When such molecules are synthesized or broken down, changed from one form into another as they move through the ecosystem, the degraded in the same way in which energy moving through a food chain is lost. The cycling of earth material through living systems and back to the earth is called **biogeochemical cycling.** Of the 92 naturally occurring chemical elements, about 40 are essential to the existence of living organisms and are known as **nutrients**. The maintenance of life on this planet is ultimately dependent on the repeated recycling of inorganic materials in more or less circular paths form the abiotic environment to living things and back to the environment again. Such cycling involves a change in the elements from an inorganic form to an organic molecule and back again (Kumar, 1997).

1.4.1 The water cycle

The sun directs the water cycle, warms the water in the oceans and some of it evaporates. Ice and snow are sublimated directly with water vapor. Rising airflow, evaporation from the atmosphere, evaporation from the soil and evaporation from the soil is taken from the evapotranspiration water. Steam rises to the air and condenses into the clouds. The air currents carry clouds into the world; Cloud particles collide, grow and descend into the earth as precipitation. Some precipitation falls as snow and frozen water can accumulate as ice masses and glaciers that can store thousands of years. Most rainfall goes to the ocean or to the ground flowing land. Streams and underground water leaks accumulate and are stored as fresh water in lakes. All rivers do not flow into rivers. Most of them are pile up as infiltration. It infiltrates deeply into some water course and fills aquifers (saturated underground rocks) that store freshwater for long periods of time (see Figure 1.4).

1.4.2 The carbon cycle

Carbon is the basic constituent of living organic compound. Since energy transfer occurs as the consumption and storage of carbohydrates and fates, carbon moves through the ecosystem with the flow of energy. The source of nearly all carbon found in the atmosphere and dissolved in waters of the earth is carbon dioxide.

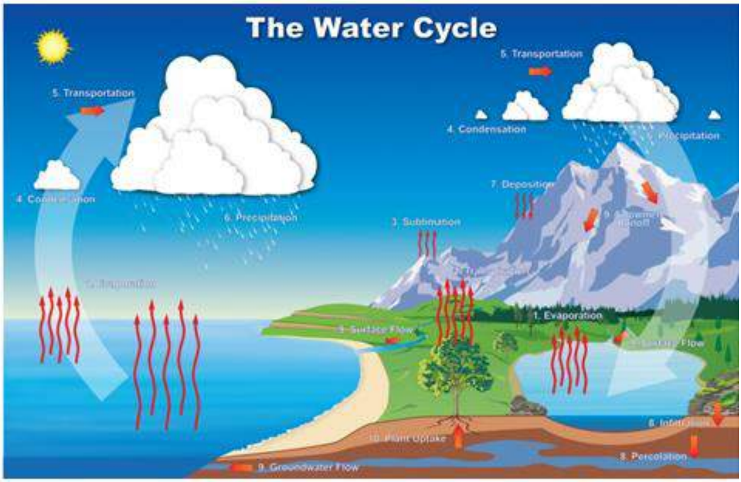

Figure 1.4. The water cycle (https://www.google.com.tr/search?q=biogeochemical+cycles)

The events in carbon cycle are the opposite reactions of respiration and photosynthesis. In respiration carbohydrates and oxygen are taken to produce carbon dioxide, water, and energy. While in photosynthesis carbon dioxide and water are taken to produce carbohydrates and oxygen (see Figure 1.5).

Carbon released from respiration of plants or animals is taken up by a plant with photosynthesis. When an animal or a plant dies, the carbon contained in it is used by decomposers or it can accumulate in the environment to form coal, oil or natural gas.

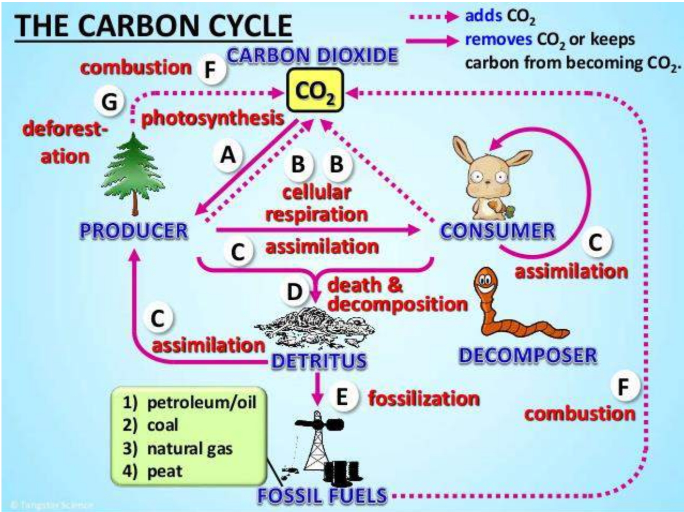

Figure 1.5. The carbon cycle (https://www.google.com.tr/search?q=biogeochemical+cycles)

1.4.3 The nitrogen cycle

Nitrogen is crucial for all organisms because it is an essential of protein and nucleic acids. The principal reservoir of nitrogen is the atmosphere, which is about 78% of the atmosphere, the largest gaseous reservoir of any element. Nitrogen gas is fixed from the atmosphere by nitrogen-fixing bacteria and photosynthetic cyanobacteria (blue-green algae). They both fix nitrogen, either in the form of nitrate or in the form of ammonia.

When the plant or animals dies, decomposing bacteria and fungi decays resulting ammonia acids to be broken down, releasing ammonia gas (NH_3). Nitrite bacteria then convert the ammonia into nitrate molecules, and nitrate bacteria in the soil produces nitrates. At this point, plants have a useable form of nitrogen again. Nitrogen removed from the nitrates in the soil by denitrifying bacteria, and returned to the atmospheric reservoir, from which, either nitrogen- fixing bacteria or electrification by lighting can release it again (see Figure 1.6).

1.4.4 The phosphorous cycle

The phosphorus cycle is a something like sedimentation, and the basic reservoir for the cycle is the phosphate rock formed in the past geological era.

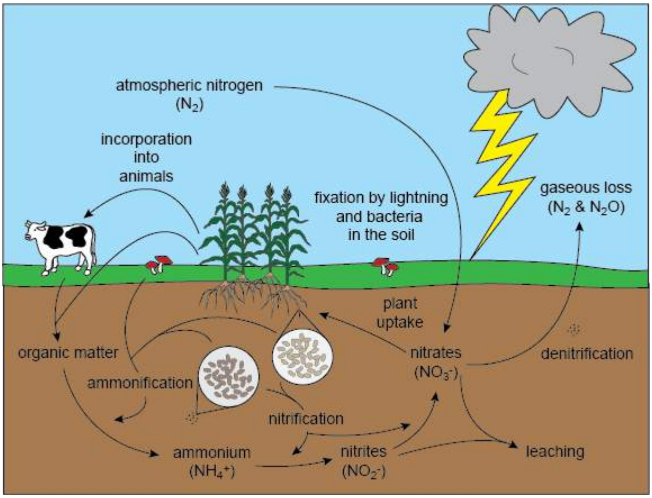

Figure 1.6. The nitrogen cycle https://www.google.com.tr/search?q=biogeochemical+cycles)

The precipitation and erosion-ending phosphate is dissolved in these reservoirs and phosphorus is used by the plants while the plants are absorbed through their roots for use in cellular synthesis. Animals receive phosphorus from plants; they return phosphorus to the dissolved phosphorus pool by normal excretion of death or body waste products. However, in dissolved form, a large number of phosphorus is lost by moving downhill to shallow marine sediments. Some of this phosphorus is sent back to the land by seabirds that release shrimp feces. Human involvement is an important factor in the phosphorus cycle (see Figure 1.7). The result is that some fresh water flows and lakes have a bioavailable phosphate excess in the runoff and drainage since phosphate in such bodies of water is generally a limiting factor in photosynthesis; it allows water plants to grow excessively. This process is called **eutrophication** (Kumar, 1997).

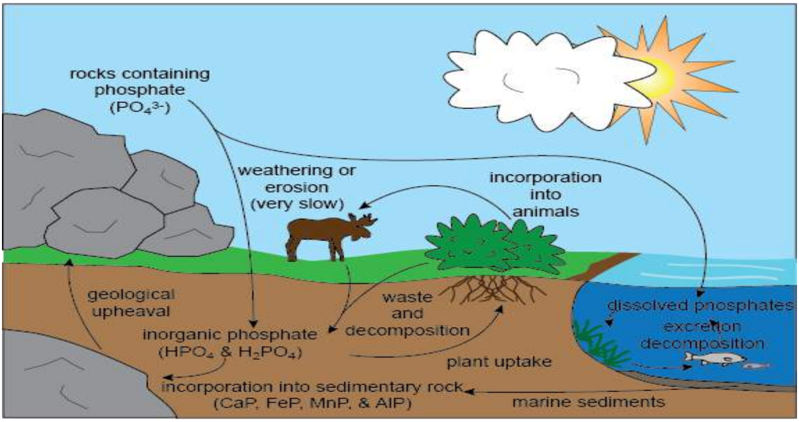

Figure 1.7. The phosphorous cycle (https://www.google.com.tr/search?q=biogeochemical+cycles)

1.4.5 The sulfur cycle

Sulfur which is an essential element of biological molecules in small quantities is mainly found on Earth as sulfates in rocks, or as free sulfur or as a combination with several metals such as lead and mercury. After digestion process bacteria emit H_2S, hydrogen sulfide, a gas that has the "rotten egg" smell which is the basic characteristic of swamps and sewage.

The largest reservoir of sulfur is in the Earth's crust as gypsum ($CaSO_4$) and pyrite (FeS_2). Freshwater contains sulfate, hydrogen sulfide and elemental sulfur; land contains sulfate; atmosphere contains sulfur oxide (SO_2) and volcanic activity releases some hydrogen sulfide into the air (see Figure 1.8).

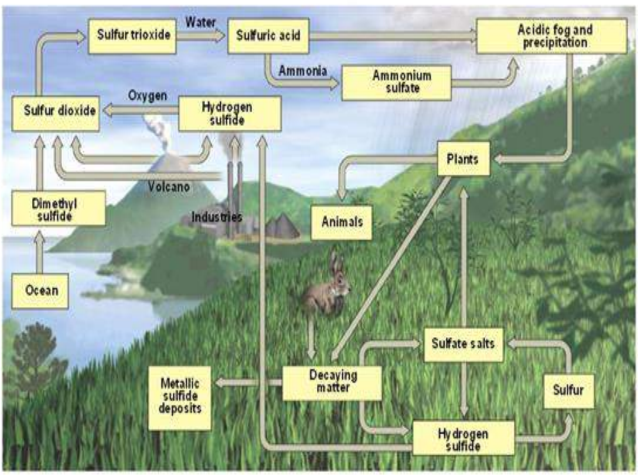

Figure 1.8. The sulfur cycle (https://www.google.com.tr/search?q=biogeochemical+cycles)

1.5 Pollutants in ecosystems

Pollutant: Any agent that adversely affects the health, survival, or activities of living organisms or that alters the environment in undesirable ways.

Persistent Organic Pollutants (POPs) are synthetic organic compounds used in various products (from electronics to automobiles) that resist environmental degradation and have been found to adversely affect the environment. Include PCBs and DDT.

How do pollutants enter the environment?

Point sources: Specific locations of highly concentrated pollutant discharge, such as factories, power plants and sewage.

Nonpoint sources: Scattered, diffuse sources of pollutants, such as runoff from farm fields and construction sites.

Factors influencing the movement of a pollutant through an ecosystem:

- Solubility of the pollutant determines how, where and when a pollutant will move through the environment.
- Water soluble pollutants move rapidly and widely through the environment.
- Fat soluble pollutants generally need a carrier to move through the environment and into and within the body.
- Once inside the body, fat-soluble pollutants penetrate readily into tissues and cells where they accumulate

and are stored as lipid deposits that are protected from metabolic breakdown.

- Fat-soluble pollutants may persist for many years.
- The persistence of a pollutant is how long it takes to breakdown and be removed from the ecosystem.
- Plastics and chlorinated hydrocarbons are resistant to degradation.
- POPs are, by their nature, quite persistent and therefore resistant to degradation.

Pollutants in the food chain: Bioaccumulation: Process by which cells selectively absorb and store a great variety of molecules by accumulating nutrients and essential minerals, by absorbing and storing harmful pollutants and by increasing concentration of a pollutant from the environment to the first organism in a food chain.

Biomagnification: Process by which the effects of pollutants are magnified in the environment through food chain (see Figure 1.9). Some pollutants are very stable and resistant to metabolic degradation; they can remain for a long time inside organism. When an organism is consumed by a member of a higher trophic level, the consumer is only able to assimilate roughly 10% of the biomass of the prey (10 % Rule) while much of the pollutant is passed on from prey to consumer due to solubility. Therefore, as the pollutant moves up the food chain the concentration of the pollutant in the body tissue increases dramatically.

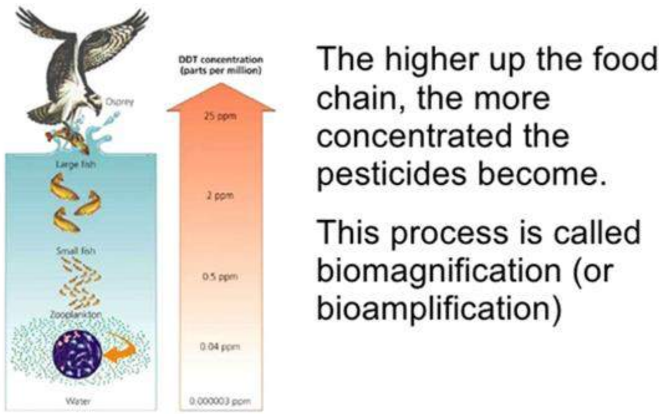

Figure 1.9. Biomagnification (https://www.google.com.tr/ search?q=biogeochemical+ cycles

Movement of pollutants: Advection, diffusion and dispersion are main processes that transport the contaminants away from the source (see Figure 1.10).

Advection: Moving along with air in the atmosphere or water in a water body. Pollutant moves along at velocity of flowing air or water.

Diffusion: Diffusion is the process through which pollutant molecules move through air or water. What causes (molecular) diffusion? At a given temperature (e.g. 20^{o}C), the molecules have a certain energy which keeps them moving. As the molecules move, they eventually strike other molecules. Striking another molecule changes the path in which pollutant molecule was initially going. Diffusion moves pollutants from high concentration to low concentration, spreading them out Best example for diffusion is; if you put a small amount of dye into a beaker full of water by not creating currents, the dye will slowly spread out until the water becomes uniformly colored (dye must be of same density as water or else it may sink or float, which is an advective process, (adopted from https://www.coursehero.com/file/219914/esm222-08-9-movement)

Dispersion: Buildings, rocks in river, sand grains in aquifer causes additional spreading of pollutants. Wind and water currents also contribute to spreading.

Retardation: A pollutant that sorbs onto soil is slowed down with respect to the velocity of the water or air phase. It takes longer for the pollutant to travel a given distance than water does. Pollutants attached to moving particles (colloids) can also sorb and desorb.

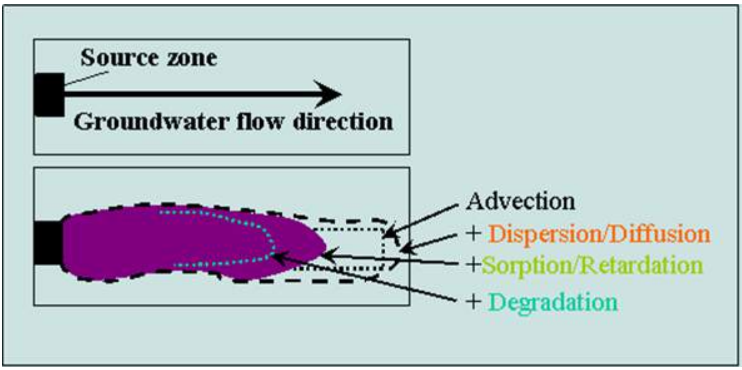

Figure 1.10. Transport process of contaminants in groundwater (https://www.coursehero.com/file/219914/esm222-08-9-movement.)

References:

Ambelu A., Deboch B., & Lenjissa D., (2007). Lecture Notes on Ecology, Jimma University, in collaboration with the Ethiopia Public Health Training Initiative, The Carter Center, the Ethiopia Ministry of Health, and the Ethiopia Ministry of Education.

Kumar, H.D. (1997). Modern Concepts of Ecology. 8th Edition, USA, Vikas Publication House.

Web page (2017), retrieved from https://www.coursehero.com/file/219914/esm222-08-9-movement.

Web page (2017), retrieved from https://www.google.com.tr/search?q=biogeochemical+cycles

CHAPTER 2

ECOLOGICAL FOOTPRINTING FOR ENERGY SYSTEMS

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Abstract: With the increase in population and increases in consumption in many parts of the world, humanity's ecological burden on the planet have increased and natural resources become insufficient to serve to all our demands. Thus nature's capacity becomes incapable of absorbing much of the pollution generated. There is a need for systemic, crosscutting assessments, which can address and compare the competing demands on the planet's limited resources. Depending on that, "Ecological Footprint" (EF) that identifies a specific ecological budget – biocapacity – and the extent to which human demands for biocapacity approach or exceed this budget will be discussed in this chapter. A "carbon footprint" (CF) which is the biggest component of ecological footprint that deals with resource usage but focuses strictly on the greenhouse gases released due to burning of fossil fuels which is directly related to conventional energy production systems will be explained. Finally alternative energy systems will be compared in terms of EF and CFs.

Learning objectives:

- At the end of this chapter, the student will learn:
- Importance of ecological and carbon footprints (need for EF and CF)

- Definitions of ecological and carbon footprints and related terms
- Limitations in ecological and carbon footprints calculations
- Components of ecological footprint
- Comparison of ecological footprints of denergy production systems

2.1. Ecological footprint

2.1.1. Need for ecological footprinting

Soil, water, air, minerals and plants are a few of the natural resources that make life possible on Earth. The energy that powers our cells, provides basic needs; clothings, nutrients that make up our bodies, the ecosystem services that clean our water and air, regulate climate are all provided by the natural resources. Human wellbeing depends on the capacity of the earth's natural systems to provide ecosystem goods and services. The ecosystem services are summarized in Figure 2.1 below.

Figure 2.1. Ecosystem Services (http://www.unepfi.org/fileadmin/documents/bloom_or_bust_report.pdf)

However, with the increase in population and increases in consumption in many parts of the world, humanity's ecological burden on the planet have increased and natural resources become insufficient to serve all our demands. Collapsing fisheries, carbon-induced climate change, deforestation and the loss of cropland to erosion and salinization are some of the most prominent examples of pressures that threaten the ability of ecosystems to continue producing critical renewable resources and services. Particularly since the mid-20th century, we are endangering a number of key environmental systems and exceeding “carrying capacity” of the earth. By carrying capacity, we mean the nature’s maximum capacity to support human population (in terms of food, water, habitat, energy) and it’s activities. Unfortunately, nature’s capacity becomes incapable of absorbing much of the pollution generated. According to “World Footprint” report of Global Footprint Network (November 2015), today humanity uses the equivalent of 1.6 planets to provide the resources we use and absorb our waste.

Along this line, it is certainly needed to observe, understand and/or confront with the concrete impacts of environmental problems, natural deterioraiton and resource depletion in order to understand the importance of the problem. “Measurability” of the human pressure on ecosystems helps people to recognize the environmental crisis. Empirical measurements have thus to be sought to understand the driving forces behind these impacts and find ways to reduce them while maintaining economic and societal well-being (Galli A. et al., 2015).

Ecological Footprint Accounting (EFA) has been used as a first approximation of the overall human pressure on Earth’s ecosystems (Galli 2015; Lin D. et al., 2015; Wackernagel M. et al., 2014). Ecological footprint (EF) is a necessary management tool to estimate if humanity’s rate of consumption exceeds earth’s carrying capacity or not; the extent to which human society stays within or exceeds the regenerative capacity of the planet.

2.1.2. Ecological footprint and related terms

The **ecological footprint** of a designated population is the area of productive land and water ecosystems required to produce the resources that the population consumes and assimilate the wastes that the population produces, wherever on Earth the land and water is located (Wackernagel M. and Rees W., 1996). It measures the requirements for productive areas; croplands, grazing lands, forests, marine areas, built-up land for housing and infrastructure. This resource accounting is similar to life cycle analysis wherein the consumption of energy, biomass (food, fiber), building material, water and other resources are converted into a normalized measure of land area called 'global hectares' (gha). A **global hectare** is a biologically productive hectare with world average biological productivity for a given year. Global hectares are needed because different land types have different productivity. A global hectare of, for example, cropland, would occupy a smaller physical area than the much less biologically productive pasture land, as more pasture would be needed to provide the same biocapacity as one hectare of cropland. Because world bioproductivity varies slightly from year to year, the value of a gha may change slightly from year to year. (WWF, 2016). Recently, it has been shifted to measure the land use that is required for population activities taking place on the biosphere within a given year while considering the prevailing technology and resource management of that year (Borucke M. et al., 2013). These productivity-weighted biologically productive hectares allow researchers to report both the biocapacity of the Earth or a region, and the demand on biocapacity (the Ecological Footprint). The "**equivalence factor**" is the key factor that allows land of different types to be converted into the common unit of global hectares. These equivalence factors are based on assessments of the relative productivity of land under different land types in any given year. In the most current EF accounts, an index of suitability for agricultural production is used as a proxy measure of the productive capacity of different land types. Within a given land type, such as cropland, the ability of an area to produce useful goods and services can vary dramatically based on factors such as climate, topography, or prevailing management. “**Yield factors”** allow different areas of the same land type to be compared based on the common denominator of yield. National yield factors for pasture, for example, compares the productivity of average pastures in a specific nation to world-average pastures. These yield factors convert one hectare of a specific land type, such as pasture, within a given nation into an equivalent number of world-average hectares of that same land type. (http://www.footprintnetwork.org/faq/).

If a population’s Ecological Footprint exceeds the region’s biocapacity, that region runs an **ecological deficit** or it is called as **ecological overshoot**. Its demand for the goods and services that its land and seas can provide—fruits and vegetables, meat, fish, wood, cotton for clothing, and carbon dioxide absorption—exceeds what the region’s ecosystems can renew. A region in ecological deficit meets demand by importing, liquidating its own ecological assets (such as overfishing), and/or emitting carbon dioxide into the atmosphere. The consequences of “overshoot” are already clear: habitat and species loss, and accumulation of carbon in the atmosphere (Tittensor D.P. et al., 2014). If a region’s biocapacity exceeds its EF, it means, it has an **ecological reserve**.

Figure 2.2 shows the trends of world's EF and biocapacity (in gha), from 1961 to 2012 . It is obvious that, a global overshoot situation has begun in 1970s and since then, humanity's demand for the Earth's regenerative capacity has steadily increased. Human demand on the Earth's regenerative capacity is projected to continue growing steadily and to exceed such capacity by about 75 per cent by 2020. Changing this course by design will require considerable shifts in technology, infrastructure and behaviour, in order to support less resource-intensive production and lifestyles (WWF, 2016)

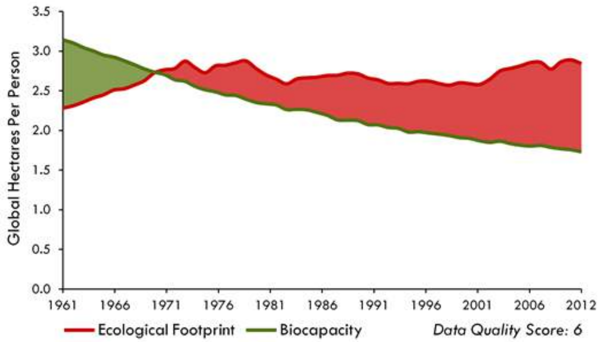

Figure 2.2. World's Ecological Footprint and Biocapacity (in gha)(http://www.footprintnetwork.org/content/images/trends/2016/world.png)

Contribution of human uses is given in Figure 2.3.

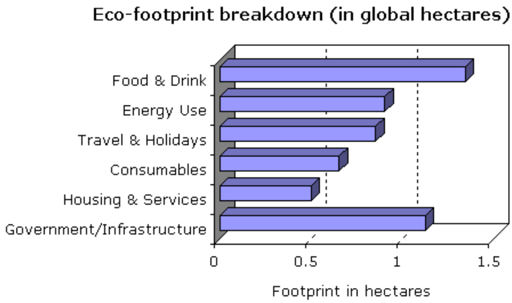

Figure 2.3. Breakdown of Ecological Footprint (in gha) (http://info.cat.org.uk/questions/low-impact-living/what-ecological-footprint/)

2.1.3. Use of EF values

Ecological Footprint findings show how far humanity is from a safe and just operating space (Dearing J.A. et al., 2014) as a result of overusing natural resources and ecological services which has immediate relevance as an early warning for environmental protection and sustainability.

Ecological Footprint findings:

- Inform about to what extent a country/city/person/facility uses more or less than its available land
- Enable to discuss possible scenarios for the future of human demand and ecosystem

- Bring humanity out of overshoot and onto a potentially sustainable path to manage the consumption of food, energy, and maintaining or increasing the productivity of natural and agricultural ecosystems
- Are they used as a useful tool to educate people about carrying capacity and overconsumption to lead behavioral change towards nature

- Engage public actors in transforming Footprint diagnoses into sector-specific policy prescriptions and economic decision-making.

The Footprint is primarily useful as a planning tool when facing decisions concerning long-term investments.

However it should be kept in mind that; EF calculations have some limitations (Galli A. et al., 2016). EF uses just one lens – biocapacity – to track the human dependence on complex and interdependent environmental systems. It does not address all environmental pressures and consequences that are related to human consumption, such as pollution and loss of habitat (Galli A. et al., 2012). It is an approach that takes a snapshot of a community’s resource use at a particular moment, historical ecological data is needed to allow comparisons across space and time (Marazzi L., 2017). It provides insight on a minimum condition for sustainability: whether or not human consumption activities fit within the biological threshold defined by the Earth’s biocapacity (Lin et al., 2015). The Ecological Footprint is not only a measure of human impact, but also is a predictive measure of the sustainability of specific management practices. It is an accounting system that compares human demand on Earth's ecosystems to what these ecosystems are able to renew. Given this scope and knowledge, Ecological Footprint accounts should be used as a necessary but not sufficient minimum reference framework that approximates all of humanity's demands on nature that compete for biologically productive area (Galli, 2016).

2.1.4. Components of ecological footprint

In ecological footprint accounting, six footprint components are distinguished in accordance with major land use types. All of these are built on six ecosystem services for human well-being: plant-based food production, livestock-based food production, fish-based food production, timber production, living space supply, and energy-related CO_2 absorption (Galli A. et al., 2012; Kitzeset J. Et. al., 2009). Components are weighted with equivalence factors before being added up to the total. The ecological footprint, therefore, is a land-based, composite indicator (Wackernagel and Rees, 1996; Steen-Olsen et al., 2012). Figure 2.4 shows and explains components of EF.

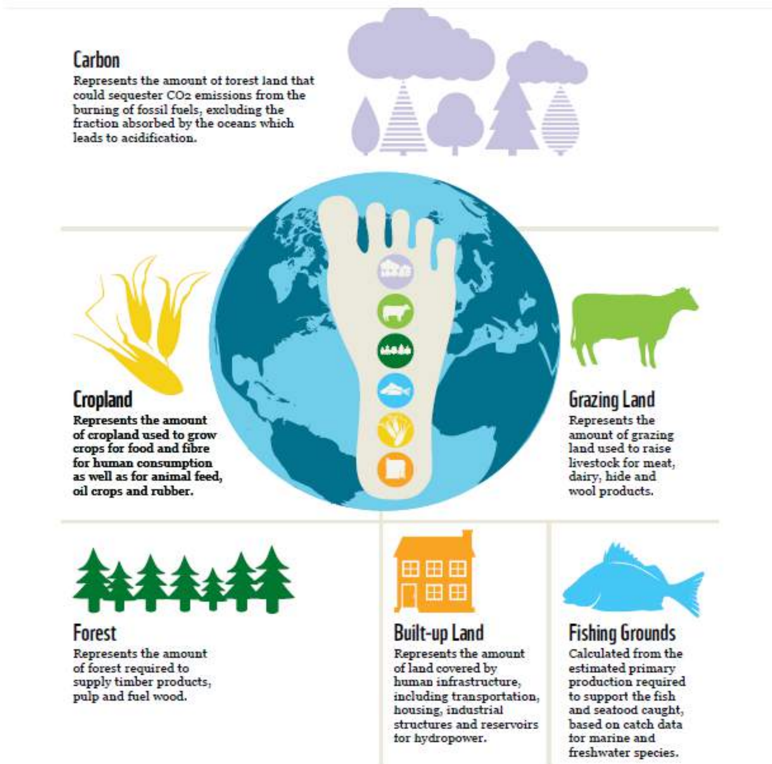

Figure 2.4. Components of Ecological Footprint (WWF, 2016)

2.2. Carbon footprinting

Separating the ecological footprint into its individual components demonstrates how each one contributes to humanity's overall demand on the planet. Probably the best-known component of the EF is the Carbon Footprint

(CF) at the global level. Because it is the largest footprint; the increase in anthropogenic demands was most prominent for the CF (+260% due to the growing use of fossil fuels, electricity and energy-intensive commodities) and the cropland Footprint (+125%) components (WWF, 2016). The increasing interest in CF comes as a result of growing public awareness of global warming.

"Carbon Footprint" might be defined as; the land required to absorb the CO_2 that is released from the burning of fossil fuels and other sources (WWF, 2016). This is commonly used to describe the total amount of CO_2 and other greenhouse gas (GHG) emissions for which an individual, group or organisation is responsible. Definitions vary in terms of which activities and greenhouse gases should be included within the scope of a carbon footprint assessment, and the level of detail. Some carbon footprint definitions only mention carbon dioxide (Global Footprint Network, 2007). Other definitions and methods include all Kyoto greenhouse gases and measure emissions in terms of 'carbon dioxide equivalents', for example Carbon Trust (2007).

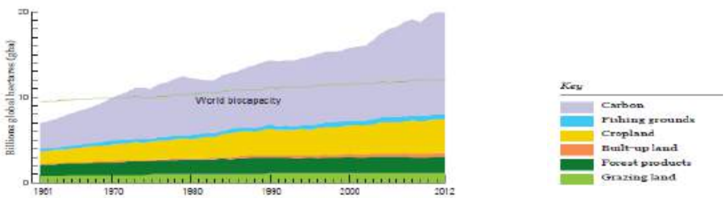

Figure 2.5. Global Ecological Footprint by Component (WWF, 2016)

Figure 2.5 shows “carbon” is the dominant component of humanity’s EF (ranging from 43 per cent in 1961 to 60 per cent in 2012). Its primary cause has been the burning of fossil fuels – coal, oil and natural gas. The green line represents the Earth’s capacity to produce resources and ecological services (i.e., the biocapacity). It has been upward trending slightly, mainly due to increased productivities in agriculture (Global Footprint Network, 2016). Data are given in global hectares (gha). (WWF, 2016)

Despite its name, the Carbon Footprint is not expressed in terms of area. The total amount of greenhouse gases is simply measured in mass units (kg, t, etc.) and no conversion to an area unit (ha, m^2, km^2, etc.) takes place. Any conversion into a land area would have to be based on a variety of assumptions that would increase the uncertainties and errors associated with a particular Carbon Footprint estimate. When only CO_2 is included, the unit is kg CO_2; if other GHGs are included the unit is kg CO_2-e, expressing the mass of CO_2- equivalents. Those are calculated by multiplying the actual mass of a gas with the global warming potential factor for this particular gas, making the global warming effects of different GHGs comparable and additive.

However, within a full Ecological Footprint calculation, data on carbon dioxide emissions are translated into the area, in global hectares, required to absorb these carbon emissions (Monfreda C. et al., 2004). This global hectare-based carbon footprint can then be added to other components of the EF, such as the cropland cootprint and fishing grounds footprint, to obtain the total Ecological Footprint of a population or activity.

It is widely accepted that the lifecycle assessment (LCA) is a useful tool for calculating the carbonfootprint, especially at the product level (Wiedmann T. and Minx J., 2008). Nevertheless, criticisms toward the carbon footprint remain. A prominent one is the view expressed by some observers that the huge demand for detailed data compromises the quality of outcome, especially in those situations where extremely limited data for use at micro- or meso-scale accounts lead to underestimation (Chakraborty D. and Roy J., 2013; De Benedetto L. and Klemeˇs J. , 2009). Another criticism is that the lack of consideration of carbon sequestration land runs the risk of disregarding the terrestrial feedback processes such as abrupt degradation of forestor changes in the distribution of vegetation and oceanic fluxes that further affect the global carbon cycle, which may have sub-sequent detrimental impacts on climate (Fang K. et al., 2013).

2.3. Ecological footprints of energy production systems

Energy use and demand are increasing continuously due to the population growth. All forms of energy generation have an environmental impact on our air, water and land, but it varies. Residential, work place, leisure, and service sectors still use large amounts of energy and produce large emissions of CO_2. Considering that about 80% of our current primary energy comes from fossil energies, environmental impacts of energy producing systems becoming more and more important. In addition to the growing need for energy, the risk to the environment and human health from climate change caused by CO_2 emissions is an international scientific and policy challenge.

To evaluate the relative burden of energy systems within the environment, full energy supply chains need to be considered on a lifecycle basis, including all system components, and across all impact categories. As a resource accounting tool, EF may help to determine major contributors to environmental impacts from energy production in total and to compare the impacts of alternative energy systems; fossil fuels, renewables and nuclear.

While doing this, it should be taken into account:

- how much physical space is required to generate the energy,
- how this requirement changes among non-renewable and renewable energy sources,
- what are the ecological costs of those space needs,
- what needs to be monitored to understand the effect of energy-generating facilities on ecosystems, human health, and social systems.

In this section, environmental impacts of fossil fuels, renewables and nuclear energy systems are discussed and compared in terms of lifecycles, EFs and CF values.

2.3.1. Comparison of energy systems

There is a methodological challenge in comparing different energy technologies that is caused by the fact that they are based on widely different sources and techniques to exploit these sources.

Conventional energy technologies are mostly based on fossil resources like coal, crude oil and natural gas. These technologies usually exhibit their largest pressure on the environment during operation by emitting CO_2 into the atmosphere and thus changing the global carbon flow systems with grave consequences for the global climate.

However renewables such as wind power, solar heat and photovoltaic and hydropower have envionmental impacts especially linked to the construction and installation of the equipment like PV panels, wind turbines and solar collectors. “Renewable resource-based energy technologies” represent a very diverse range of technologies with large differences in both their overall pressure as well as the distribution of this pressure into different impact categories.

There are several methodologies that can be used to assess environmental impacts such as MIPS (material input per service unit), CML-Method, CED (cumulative energy demand) and ecological footprint. Ecological spatial footprint of renewable energy types can be used in conjunction with CO_2 footprint models to understand the real costs (and benefits) of renewable energy for societies (Burger J. and Gochfeld M., 2012).

For a complete environmental impact assessment an analysis tool is needed which can evaluate material flows, energy flows and emissions. This calls for a measure that is highly aggregated (to allow comparison) but evaluates different impacts in a transparent scientifically based way.

Here, results of the comparative studies for the environmental impacts of the energy systems using life cycle assesment and ecological footprints will be summarized. Table 2.1 shows ranges of the lifecycle CO2e emission per kWh of electricity generated for the electric power sources considered (all technologies except the biofuels).

Table 2.1. Equivalent carbon dioxide lifecycle, opportunity-cost emissions (Jacobson M.Z., 2008).

Technology	Lifecycle	Opportunity cost emissions due to delays	War/terrorism (nuclear) or 500 yr leakage (CCS)	Total
Solar PV	19–59	0	0	19–59
CSP	8.5–11.3	0	0	8.5–11.3
Wind	2.8–7.4	0	0	2.8–7.4
Geothermal	15.1–55	1–6	0	16.1–61
Hydroelectric	17–22	31–49	0	48–71
Wave	21.7	20–41	0	41.7–62.7
Tidal	14	20–41	0	34–55
Nuclear	9–70	59–106	0–4.1	68–180.1
Coal-CCS	255–442	51–87	1.8–42	307.8–571

Table 2.1 indicates that, coal has the highest impact (almost 10 times of PV panels). Secondly, the impact of solar PV is higher and very close to geothermal. The impact range of nuclear is very wide as mentioned in section 2.4 and diffucult to compare. The climate-relevant lifecycle emissions occur only during the construction, installation, maintenance, and decommissioning of the technology. For geothermal, emissions also occur due to evaporation of dissolved CO_2 from hot water in flash- or drysteam plants, but not in binary plants. For corn ethanol, cellulosic ethanol, coal-CCS, and nuclear, additional emissions occur during the mining and production of the fuel. For biofuels and coal-CCS, emissions also occur as an exhaust component during combustion (Jacobson, 2008).

The study done by Kettl, et. al. (2011) Sustainable Process Index (SPI) was used to solve questions about ecological feasibility of different technologies and their resources. He examined if renewable based systems have indeed a lower impact to the environment compared to fossil driven energy technologies if the whole life cycle is considered. Results (see Figure 2.6) indicated that, even a “clean” fossil-based technology as natural gas turbines exert a higher pressure than all renewable resource-based alternatives. The difference here is not only persentages but also factors, with natural gas derived electricity (with 41.0m2a/MJ) exerting 10.8 times the impact of the biogas technology (with 3.8m2a/MJ) and still two times the impact of the “worst” renewable based technology photovoltaics (PV with 19.9m2a/MJ).

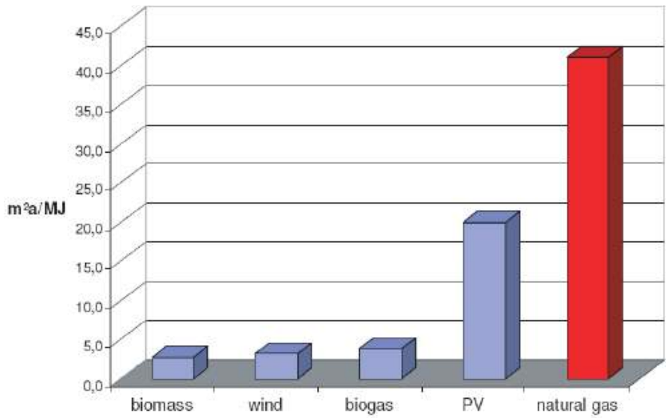

Figure 2.6. Comparison of footprint areas for energy systems (Kettl, et. al., 2011)

*The unit m2a/MJ means footprint area per year of production and produced MJ.

Finally, it should be kept in mind that; Nugent and Sovacool (2014) critically reviewed 153 lifecycle studies of renewables, especially wind and solar. It is found out that; “a range of emissions intensities for each technology, from a low of 0.4g CO2-eq/kWh to a high of 364.8g CO2-eq/kWh for wind energy,with a mean value of 34.11g CO2-eq/kWh. For solar energy, it finds a range of 1 g CO2- eq/kWh to 218g CO2-eq/kWh”. That means; many LCA tends to be subjective in its decision criteria and seems to be influenced by different internal and external factors. Even objectively done, bias-free LCAs can give diametrically opposing results due to differences in their methodology as exemplified.

2.4. Nuclear energy

Nuclear power generation has a relatively small carbon footprint; since there is no combustion, (heat is generated by fission of uranium or plutonium), operational CO_2 emissions account for <1% of the total. Most emissions occur during uranium mining, enrichment and fuel fabrication. Decommissioning accounts for 35% of the lifetime CO_2 emissions, and includes emissions arising from dismantling the nuclear plant and the construction and maintenance of waste storage facilities. The most energy intensive phase of the nuclear cycle is uranium extraction, which accounts for 40% of the total CO_2 emissions. (Parliamentary Office of Science and Technology, 2006). The results of Poinssot et. al., 2014 highlight again that nuclear energy has the lowest impact in terms of GHG emission (about 5.3 g/kWhe). This is 100 times lower than fossil energy and 8 times lower than photovoltaic energy. When considering atmospheric pollution (SOx and NOx), nuclear energy has higher values than hydro and wind electricity, but still lower than PV and obviously fossil energies. Regarding potential impact indicators (acidification, eutrophication and POPC), nuclear energy figures are systematically in second best position, with impact higher than hydroelectricity but lower than any other energy sources, even wind-power and PV. Similarly, although mining has a strong impact, nuclear energy land-use is anticipated to be the lowest. Conversely, figures for water consumption and withdrawal of nuclear energy are significantly higher than other energy sources, in the range of fossil energies. Finally, technological waste produced by nuclear energy is about 1000 lower than fossil energies but still remains

10 times higher than renewables. This is directly related to the large size of the infrastructures (plants.) which are needed to operate the whole fuel cycle (in particular the reactors).

However, catastrophic events at nuclear plants such as Chernobyl (USSR in 1986) and Fukushima (Japan, 2011) have the potential for high impact human and ecological effects, both at the regional and global level. The public generally has considerable “fear” or concern about the potential for low probability, high consequence events. The full life-cycle cost of operation of a nuclear facility may be high. Life cycle costs include mining, milling, enrichment, and fabrication (with attendant ecological and human health effects), safe transportation corridors requiring new infrastructure, and the unsolved problem of waste disposal, which may entail significant subterranean land use (Burger J. and Gochfeld M., 2012).

In fact, there is no consensus in the scientific literature as to the carbon footprint of existing nuclear reactors. The studies for the determination carbon footprint for nuclear energy is a problematic area. Methodological and contextual inconsistency between the many published nuclear power LCAs has resulted in widely ranging results, making direct comparison difficult and thwarting a clear, collective understanding (Warner E. and Garvin H., 2012). Results are uncertain and speculative. In 2012, four years after Sovacool's (2008) paper, Ethan Warner and Garvin Heath found 274 papers containing nuclear LCAs . They filtered them down to 27 for further consideration. These yielded 99 estimates of carbon footprints which the authors describe as "independent".Their data for carbon emissions ranged from 4 to 220 gCO_2/kWh. They did not report an average but rather a median value: half the estimates were below 13 gCO_2/kWh. These two reviews of the published literature, produced conflicting results. One suggests the carbon footprint is above the CCC limit, the other well below (http://www.theecologist.org/News/news_analysis/2736691/false_solution_nuclear_power_is_not_low_carbon.html).

Nuclear power's status as a low-carbon source of electricity is doubtful: while it compares favourably to traditional fossil fuels such as coal, the logistical chain required for extracting and processing uranium, plant construction and plant decommissioning create a carbon footprint for nuclear power that is significantly greater than renewable sources. (https://www.cse.org.uk/downloads/reports-and publications/planning/renewables/common_concerns_about_wind_power.pdf)

Decreasing or even eliminating dependence on fossil fuels and turning towards renewable energy sources offer a great opportunity to shrink humanity's footprint to a size the earth can support.

References:

Borucke, M., Moore, D., Cranston, G., Gracey, K., Iha, K., Larson, J., Lazarus, E., Morales,J.C., Wackernagel, M., Galli, A. (2013). Accounting for demand and supply of thebiosphere's regenerative capacity: the national footprint accounts' underlying methodology and framework. Ecological Indicators, (24), 518–533.

Galli, A., Lin, D., Wackernagel, M., Gressot, M. and Winkler, S. (2015). Brief for GSDR – Humanity's growing Ecological Footprint: sustainable development implications. Global Footprint Network.

Burger, J. and Gochfeld, M. (2012). A conceptual framework evaluating ecological footprints and monitoring renewable energy: wind, solar, hydro, and geothermal. Energy and Power Engineering, (4), 303-314.

Chakraborty, D. And Roy, J. (2013). Energy and carbon footprint: numbers matter in low energy and low carbon choices. Current Opinion in Environmental Sustainability, (5), 1–7.

De Benedetto, and L., Klemes,ˇ J. (2009). The environmental performance strategy map: an integrated LCA approach to support the strategic decision making process. Journal of Cleanar Production, (17), 900-906.

Dearing, J.A., Wang, R., Zhang, K., Dyke, J.G. and Haberl, H. (2014). Safe and just operating spaces for regional social-ecological systems. Global Environmental Change, (28), 227-238.

Fang, K., Heijungs, R. and De Snoo, G. (2013). The footprint family: comparison andinteraction of the ecological, energy, carbon and water footprints. Revue deMétallurgie, (110), 77–86.

Galli, A., Wiedmann, T.O., Ercin, E., Knoblauch, D., Ewing, B.R. and Giljum, S. (2012). Integrating ecological, carbon and water footprint into a "Footprint Family'' of indicators: definition and role in tracking human pressure on the planet. Ecological Indicators, (16), 100–112.

Galli, A. (2015). On the rationale and policy usefulness of ecological footprint accounting: the case of Morocco. Environmental Science & Policy (48), 210–224.

Jacobson, M. Z. (2008). Review of solutions to global warming, air pollution, and energy security. Energy and Environmental Science, (2), 148–173.

Kettl, K., Niemetz, N., Sandor, N., Eder, M. and Narodoslawsky, M. (2011), Ecological Impact of Renewable Resource-Based Energy Technologies. Journal of Fundamentals of Renewable Energy and Applications, (1), 1-5.

Kitzes, J., Galli, A., Bagliani, M., Barrett, J., Dige, G., Ede, S., Erb, K., Giljum, S., Haberl, H. And Hails, C. (2009). A research agenda for improving national ecological footprint accounts. Ecological Economics, (68), 1991–2007.

Lin, D., Galli, A., Borucke, M., Lazarus, E., Grunewald, N., Martindill, J., Zimmerman, D., Mancini, S., Iha, K. and Wackernagel, M. 2015. Tracking supply and demand of biocapacity through ecological footprint accounting. Sustainability Assessment of Renewables- Based Products: Methods and Case Studies, 179–200.

Marazzi, L. (2017). Our Ecological Footprint, Macat International Ltd.

Monfreda, C., Wackernagel, M. and Deumling, D. (2004). Establishing national natural capital accounts based on detailed ecological footprint and biological capacity accounts. Land Use Policy, 231-246.

Nugent, D. and Sovacool, B.K. (2014). Assessing the lifecycle greenhouse gas emissions from solar PV and wind energy: A critical meta-survey. Energy Policy, (65), 229-244.

Parliamentary Office of Science and Technology, Postnote. (2006). Carbon footprint of electricity generation. Number 268

Sovacool, B.K. (2008). Valuing the greenhousegas emissions from nuclear power: A critical survey. Energy Policy, 36(8), 2950-2963.

Steen-Olsen, K., Weinzettel, J., Cranston, G., Ercin, A.E. and Hertwich, E.G. (2012). Carbon, land, and water footprint accounts for the european union: consumption, production, and displacements through ınternational trade. Environmental Science & Technology, (46), 10883-10891.

Tittensor, D.P., Walpole, M., Hill, S.L.L., Boyce, D.G., Britten, G.L., Burgess, N.D., Butchart, S.H.M., Leadley, P.W., Regan, E.C. and Alkemade, R. (2014). A mid-term analysis of progress toward international biodiversity targets. Science 346 (6206): 241–244.

Wackernagel, M., Cranston, G., Morales, J. C. and Galli, A. (2014). Ecological footprint accounts, In: Atkinson, G., Dietz, S., Neumayer, E., Agarwala, M. (Eds.), Handbook of Sustainable Development. second revised edition Edward Elgar Publishing, Cheltenham,Glos, UK.

Wackernagel, M. and Rees, W. (1996). Our Ecological Footprint: Reducing Human Impact on the Earth. New Society Publishers.

Warner, E. and Garvin, H. (2012). Life cycle greenhouse gas emissions of nuclear electricity generation. systematic review and harmonization. Journal of Industrial Ecology, 16(1), S73-S92.

Wiedmann, T. And Minx, J. (2008). A definition of ‘carbon footprint’. In: Pertsova, C.C. (Ed.), Ecological Economics

Research Trends (pp. 1–11), Hauppauge, NY,USA: Nova Science Publishers.

WWF. 2016. Living Planet Report 2016. Risk and resilience in a new era. WWF International, Gland, Switzerland.

Web page (2017), retrieved from http://www.footprint network.org/ content/images /trends/2016 /world.png

Web page (2017), retrieved from http://www.footprint network.org/faq/

Web page (2017), retrieved from http://info.cat.org.uk /questions/low-impact-living/what-eco logical-footprint/)

Web page (2017), retrieved from http://www.unepfi.org/ fileadmin/documents/bloom_or_bust_ report.pdf

Web page (2017), retrieved from http://www.footprintnetwork .org/our-work/ecological-foot print/

Web page (2017), retrieved from http://www.theecologist.org /News/news_analysis/2736691/false_solution_ nuclear_power _is_not_low_carbon.html

Web page (2017), retrieved from https://www.cse.org. uk/downloads/reports-andpublications/ planning/renewables/ common_concerns_about_wind_power.pdf

CHAPTER 3

CONVENTIONAL ENERGY PRODUCTION SYSTEMS AND ENVIRONMENTAL IMPACTS: THERMAL POWER PLANTS

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Abstract: Energy is mainly required to meet the needs of the people and the sectors such as industry, housing and transportation. But energy has also led to pollution of the environment in a large way during production, conversion, transport and consumption, as well as indispensable benefits in our lives. Large-scale energy production and conversion systems, established in parallel with population growth and industrial development, greatly influence the ecological balance, as well as transboundary influences. The emissions from power plant or from other parts of its fuel chain are the main factors yielding the environment problems. These emissions include solid, liquid and gaseous emissions. There is no doubt that burning of fossil fuels inevitably increases the emission of nitrogen oxides (NO_x), sulphur dioxide (SO_2) and carbon dioxide (CO_2) which are clearly responsible for global

warming, acid rain formation and stratospheric ozone depletion. Ecologic, economic and social impacts of climate change, acid rain formation and ozone layer depletion will also be presented in this chapter.

Learning Objectives:

At the end of this chapter, students will be able to:

- Discuss the scopes of environmental impacts,
- Define the impacts of thermal power plant,
- Explain how thermal power plants operate,
- Describe the terms of climate change, global warming, ozone depletion and acid rain,
- Be aware the timeline of climate change, how serious is acid rain and ozone depletion,
- Explain the concept of causes and impacts of climate change, acid rain and ozone depletion,
- Be aware of the effect of human involvement on environment.

3.1 How does a thermal power plant work?

Thermal power plants use water as a working fluid. Conversion of the energy in the fuel into electrical energy forms the operation of a power plant. In thermal power stations, steam is produced by burning fuel and runs a steam turbine. After passing through the steam turbine, the steam is condensed in a condenser and recycled into the boiler to become steam (see Figure 3.1). Thermal power plants use coal, oil and natural gas as their primary fuel (http://www.electricaleasy.com/2015/08/thermal-power-plant.html).

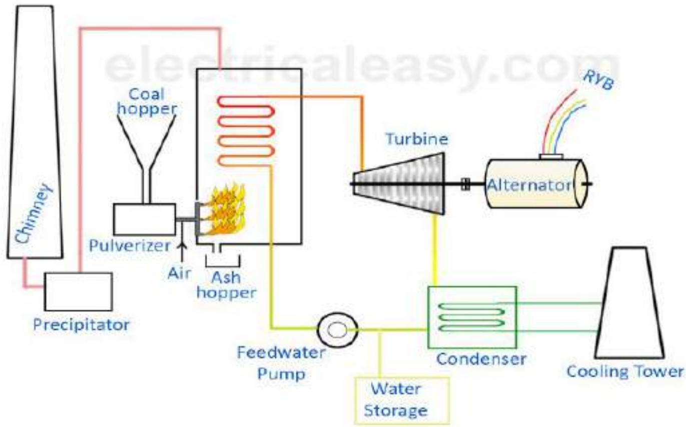

Figure 3.1. Layout of thermal power plant (http://www.electricaleasy.com/2015/08/thermal-power-plant.html)

3.2 Environmental impacts of thermal power plants

The environmental effects of the thermal power plant need to be examined both before and after the energy production. For example, for a coal using power plant, consideration should be given to the removal of coal mines, the removal of ash and the removal of the plant from final service in assessing the effects of a full fuel-chain plant. The most significant environmental impact of power plants and power generation is due to solid, liquid, gas emissions from the power plant or other parts of the fuel chain (see Figure 3.2). Gaseous emisions include flue gases (SO_2, NO_x), hydrocarbons, carbon monoxide and carbon dioxide. In thermal plants, basic liquid emission is wastewater. Significant amounts of water are used for cooling, cleaning and other processes.

The heavy metals such as Fe, Zn, Cu, Pb which are found in the fly ash due to the fuel fraction are solid emissions. They remain suspended in the air and transported to groundwater and drinking water sources by washing with rain water (www.britannica.com).

In addition to the direct emissions, there are secondary components including ozone formed from the oxides of nitrogen and volatile organic compounds (VOCs), sulphur compounds formed from sulphur dioxide, and acid rain formed from sulphur dioxide and oxides of nitrogen. Table 3.1 summarizes the types of impacts that can result from different discharges.

Coal fired, oil fired and natural gas fired power plants

Occupational hazards are

- Accidents and illnesses during production of materials, drilling, oil and gas field development, mine and plant construction;
- Accidents in transport line construction and transportation of coal and oil to the power plant;
- Accidents in operation of the power plant;
- Cancer arising from exposure to carcinogenic hydrocarbons;

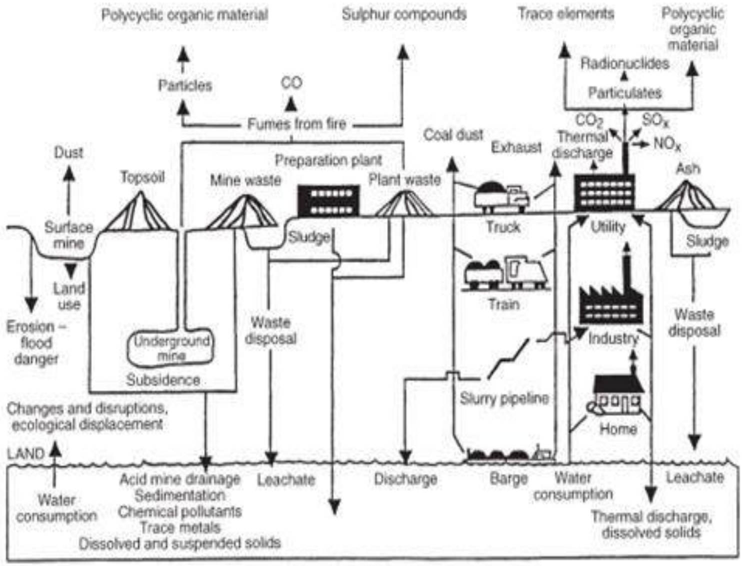

Figure 3.2. Fuel chain concept (www.britannica.com)

Table 3.1. Types of impacts that can result from different discharges (www.britannica.com)

Source of environmental impacts	Human Health		Biological Resources							
	A	B	C	D	E	F	G	H	I	J
Outdoor air										
particulates	X	X								
SO2	X	X	X	X						

NOx, nitrate, NO_2		X	X	X		X				
toxics, lead, mercury	X	X	X	X	X	X	X	X		
CO	X	X								
CO_2	X	X	X	X	X	X	X		X	
CFCs	X	X	X	X	X	X	X		X	
steam										
Secondary outdoor air										
acid aerosols	X	X								
acid deposition			X	X	X	X	X			
ozone (HCs, VOCs)	X		X	X			X			
Indoor air										
Surface water disposal										
Chemical	X	X	X		X	X	X			
Thermal					X	X				X
Solid waste disposal										
Transportation							X			X

Land use							X			X
Hazardous/PCBs	X	X			X	X		X		
Toxics in ash	X	X			X	X		X		
Construction/operation										
Facility:land use			X	X			X			X
Transmission-land use			X	X			X			X
Explosion/accident	X	X								X
Spills	X	X	X		X	X	X	X		X
Decommissioning							X	X		X
Fuel acquisition										
Extraction	X	X	X	X	X	X	X	X		X
Processing	X	X	X		X	X	X	X		X
Transportation/ storage	X	X	X		X	X	X	X		X

A:mortality; B:morbidity; C:vegetation; D: forests E:fisheries; F:aquatic; G:terrestrial; H:groundwater; I:climate change; J:aesthetics

Public hazards

- Injuries and mortality during coal, oil and gas transportation;
- Effects of inhalation of pollutants during the production of materials used in mine and plant construction and oil and gas field development;
- Effects of inhalation of pollutants from coal, oil and gas combustion released during power plant operation;
- Toxic substances released by solid and liquid wastes.
- Fires and explosions of stored oil and gas.

Environmental impacts

- Loss of land for open pit mining, or mining damage in underground mine areas;
- Acid rains;
- Pollution of water due to liquid effluents from mines;
- Pollution of water due to solid and liquid wastes from the power plant;
- Loss of forests, crops and the yield of pets and in the number of wild animals on land and water due to absorption of pollutants from coal, oil and gas combustion released during power plant operation;
- Spread of radioactivity around ash piles;
- Global warming due to CO_2 released during plant operation, material production and plant construction;
- Pollution of water during oil transportation and accidents.

3.3 Global climate change

Climate: Climate is the average of the weather conditions in one place over a wide range of time and region. The elements that determine climate in a region are temperature, wind, humidity, pressure in the air, and how they change over the course of the day and year.

Climate change: Climate change is a change in the climate as a result of human activities that directly or indirectly distort the composition of the atmosphere and the natural climate change observed in comparable time periods.

Global warming: Global warming is the increase in the average air temperatures near the surface of Earth which has been discussed over the past one to two centuries.

The intense burning of fossil fuels and the increasing of greenhouse gases in the atmosphere, especially carbon dioxide, and thus the warming of our world are defined as greenhouse effect (global warming).

Gaseous influent gases include carbon dioxide, methane, carbon monoxide, hydrocarbons and chlorofluorocarbons. It is stated that the greatest effect of global warming is that the glaciers in the poles will cause erosion and that the sea will rise and many countires will flood. As the fossil fuel consumption runs at the same rate, it shows that the temperature of our world will increase by 5 degrees over the next 50 years, which will lead to catastrophic disasters. In addition, with the increase of the earth's temperature due to the greenhouse effect, the seas will evaporate more than lakes and rivers, so there will be more rain and natural floods.

3.3.1 Causes of climate change

Volcanic activity: Volcanic activity can release large quantities of sulfur dioxide and other aerosols into the stratosphere. These compounds reduce the atmospheric transparency and thus the amount of solar radiation reaching Earth's surface and troposphere. Volcanic activity can be concentrated in such a way that gases such as water vapor, ash, SO_2, CO_2, NH_4 can change the global climate. In addition, the magma on the volcanic channels encounters carbon on earth's surface and carbon dioxide is released. This CO_2, which is mixed in the atmosphere, plays a big role in climate change. As a consequence of the volcanic eruptions, the substances released into the atmosphere may also affect the climate.

Tectonic activity: With tectonic movements (movements that take place in the earth's crust), the change of the ground formations causes the ocean and air currents to change, and large-scale climate changes can happen. Tectonic activity also influences particularly carbon dioxide concentrations.

Greenhouse gases: Greenhouse gases are compounds that support the greenhouse effect, are in the atmosphere and have the most heat retention feature. These gases can absorb infrared radiation emitted from Earth's surface and reradiate it back to Earth's surface, thus contributing to the phenomenon known as the greenhouse effect. In this way, greenhouse gases increase the temperature in the atmosphere and cause global warming and therefore climate change through greenhouse effect. Today, the main greenhouse gases are known as carbon dioxide (CO_2), chlorofluorocarbons (CFC's) and halons, methane (CH_4), diazotmonoxide (N_2O) and ozone (O_3).

Water vapour: Warming of the surface of the earth and the lower atmosphere triggers the greater evaporation rate of water from the surface. In the lower atmosphere, greater concentration of water vapour absorbs high amount of longwave radiation and emits it downward.

Carbon dioxide: CO_2 is the most heat-holding gas in the air. Amount of atmospheric CO_2 depends on the volcanoes activity, the combustion and natural decay of organic matter, and respiration by aerobic organisms. The increase in the amount of CO_2 and other gases holding heat causes the atmospheric heat to rise. It is worried that this could lead to climate changes that would have serious consequences such as the melting of the glaciers and the rise of the oceans.

Methane: Methane (CH_4) is the second most important greenhouse gas. It is involved in atmosfere with various human and animal activities. Methane has heat retaining property. It has a considerably shorter residence time in the atmosphere than CO_2.

Surface-level ozone and other compounds: The amount of ozone varies depending on latitudes and elevations in the atmosphere. Surface ozone (O_3) is a result of air pollution and it needs to be distinguished from naturally occurring stratospheric O_3. It decreases in the stratosphere layer due to greenhouse effect and increases in areas near the earth. The use of chlorofluorocarbon gases affects ozone concentration. Normally, UVB radiation reaches the lower layers of the atmosphere and some of it is trapped by the earth's surface. Biologically harmful effects are seen when the surface temperature is increased by the surface. The increase in the atmospheric levels of ozone concentration has an impact on climate change.

Aerosols: Aerosols reflect and absorb a portion of incoming solar radiation. Aerosols are readily accumulated in the atmosphere within days and spreaded by rain or snow or by settling out of the air (see Figure 3.3).

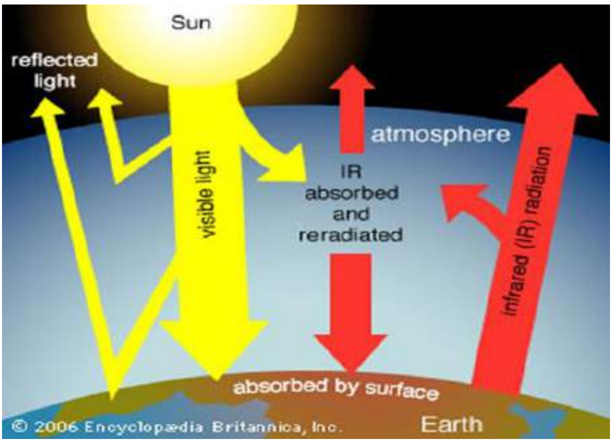

Figure 3.3. Greenhouse effect www.qa-international.com

Table 3.2 shows the timeline of the climate change.

Table 3.2. A timeline of developments in climate change (www.britannica.com)

Year	Action
1896	Svante Arrhenius constructs the first climate change model of the influence of atmospheric CO_2
1920-1925	Era of large-scale petroleum development begins with the opening of Texas and Persian Gulf oil fields
1957	Roger Revelle and Hans E. Suess write that "human beings are now carrying out a large scale geophysical experiment" in a paper examining CO_2 uptake by the oceans.
1960	The curve developed by American climate scientist Charles David Keeling begins to track atmospheric CO2 concentration.
1973	First oil shock.
1974	First evidence of chlorine chemicals being involved in ozone depletion published.
1979	Second oil shock.
1980	Keeling curve: CO_2 concentration in 1980=337 ppm.
1990	First Intergovernmental Panel on Climate Change (IPCC) report notes pattern of past warming while

	signaling that future warming is likely.
1992	United Nations conference in Rio creates UN Framework Convention on Climate Change.
1997	Kyoto Protocol is created with intent to limit greenhouse gas emissions from industrialized countries.
2000	Keeling curve: CO_2 concentration in 2000=367 ppm
2001	Third IPCC Report notes that warming resulting from GHC emissions has become very likely.
2005	Kyoto Protocol goes into effect. All major industrialized countries sign on except US.
2006	China becomes the world's largest GHG emitter.
2007	Fourth IPCC Report notes that effects of global warming are occurring.
2011	Canada withdraws from Kyoto Protocol.
2014	Keeling curve: CO_2 concentration in 2015=400 ppm
2015	Paris Climate Agreement replacing Kyoto Protocol is signed by nearly 200 countries.
2016	Paris Climate Agreement goes into effect.

3.3.2 Environmental consequences of global warming

Global warming and climate change have the potential to change the earth air temperatures that influences ecosystem and thus the biodiversity of plants, animals, and other forms of life. According to forecasts, in Europe in the late 21st century the average temperature will rise by 2.3-6.0 ° C that can poses serious risks of extinction of a large fraction of plant and animal species and severe human health problems (IPCC, 2007). Surface warming in many regions can lead to uncontrolled changes such as earlier leaf production by trees, earlier greening of vegetation, altered timing of egg laying and hatching, and shifts in the seasonal migration patterns of birds, fishes, and other migratory animals. In high-latitude ecosystems, changes in the seasonal patterns of sea ice threaten predators such as polar bears and walruses; both species rely on broken sea ice for their hunting activities.

Depending on climate change, air systems will change, resulting in water, air, product quality and quantity, ecosystem, agriculture and infrastructural problems. The effects of global warming can be counterproductive as sea level rise, seasons change and ecosystems deteriorate. Longer, severe droughts and desertification may be effective in some regions, while the severity and frequency of hurricanes, floods increase in some parts of the world due to global warming. It is expected that temperatures will increase in winter, early spring arrival, fall delay and animal migration periods. Plant and animal species that can not withstand these changes can also be reduced or completely destroyed.

3.3.3 Socioeconomic consequences of global warming

It is predicted that the amount of fresh water stored in mountain glaciers and snow will decrease, and thus more than 15 percent of the world's population will not benefit from fresh water. In addition, temperature will have a negative impact on water quality through the effects on lakes and biological activities on rivers, which will lead to even less access to safe water resources for drinking and farming. For example, warmer waters cause unpleasant algal blooms that can pose health risks to humans.

3.4 Ozone depletion

Ozone is most abundantly present in the atmosphere in two distinct tectonic plates, the troposphere and the stratosphere. These are the stratospheric ozone in the stratosphere, which is naturally found above 10-45 km from the Earth's surface and constitutes 90% of total ozone in the atmosphere (see Figure 3.4). It is vitally important because it keeps harmful ultraviolet radiation from the sun. The second one is the tropospheric ozone (industrial wastes, exhaust gas, etc.), which is human-origin, which is about 10-15 km from the ground and constitutes 10% of total ozone in the atmosphere. Tropospheric ozone ranks fourth among greenhouse gases that play a role in global climate change. Long wavelength radiation remains in the atmosphere, causing the greenhouse effect in the atmosphere to increase. Contribution to greenhouse effect in global climate change is 7%. It affects human health adversely. The ozone that reacts with other molecules in the atmosphere has various damages to living tissues of plants and animals. Nitrogen oxides (NO_X), one of the sources of malignant ozone, are predominantly composed of motor vehicles (49%), power plants (28%), industrial activities (13%) and commercial activities (5%). The ozone in the stratosphere is primarily resulted by breaking the chemical bonds within oxygen molecules (O_2) by high-energy solar photons by the process called photodissociation. Single oxygen atoms released due to phodissociation later join with oxygen molecules to form ozone.

The ozone feature in the stratosphere is absorbing ultraviolet (UV) rays that affect all living things, natural resources and agricultural products negatively. The amount of ozone in the stratosphere varies naturally throughout the year as a result of chemical processes, winds and other transport processes that move ozone molecules around the planet. The fact that the density of the ozone is too low to hold the ultraviolet rays is called the "ozone layer perforation" or “ozone depletion”. As a result of the thinning of the ozone layer; UV-b radiation is increasing and people's immune systems are damaged, leading to visual impairment and skin cancer.

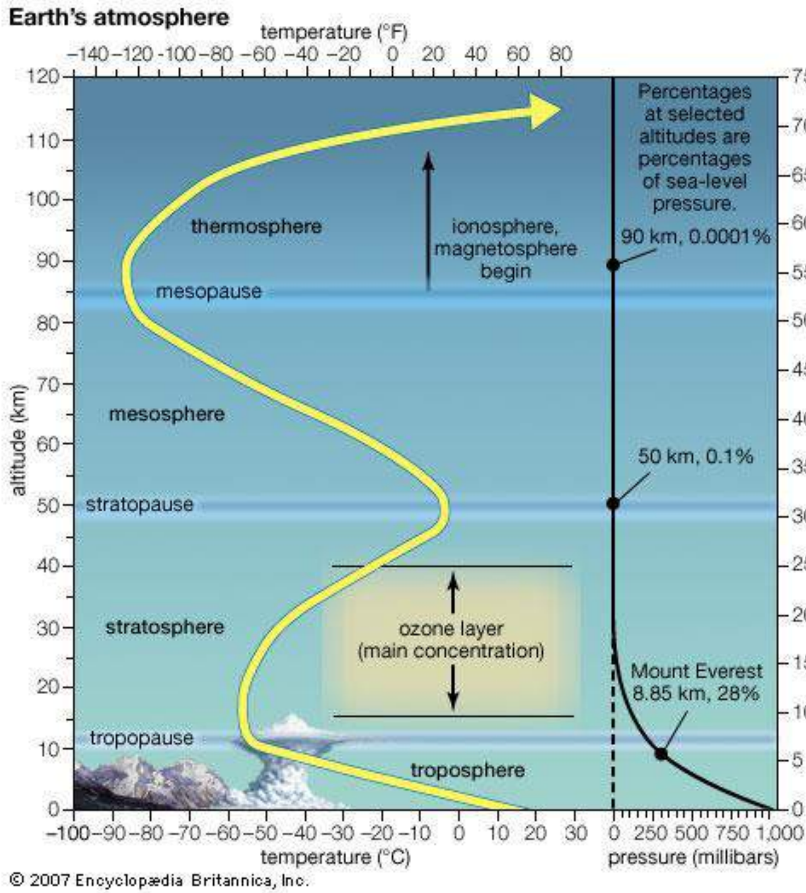

Figure 3.4. Ozone layer (https://www.google.com.tr/search ?q=ozone+destruction+mechanism)

Human activities have substantially altered the ozone layer for over several decades. The increase in the amount of chlorine and bromine in the stratosphere stimulates the ozone depletion. These chemicals destroy ozone by stripping away single oxygen atoms from ozone molecules after they removed from the chlorofluorocarbons (CFCs) and other halocarbons (carbon-halogen compounds) by UV radiation. Depletion is so extensive that so-called ozone holes form over the poles during the onset of their respective spring seasons. The chlorine atoms then react with ozone, initiating a process whereby a single chlorine atom can cause the conversion of thousands of ozone molecules to oxygen (see Figure 3.5).

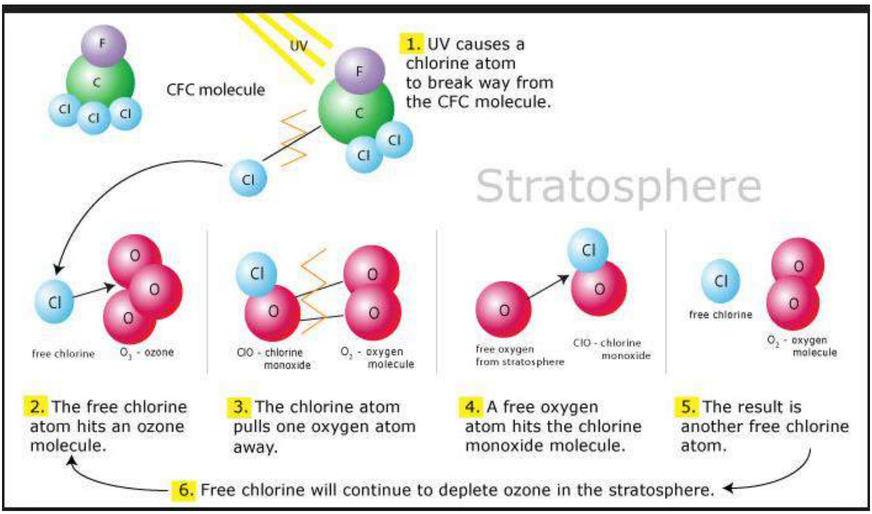

Figure 3.5. Ozone depletion mechanism (https://www.google.com.tr/search? q=ozone+destruction+mechanism)

3.5 Acid rain

The coal that is used in thermal power plants, heating and industrial establishments emits atmospheric ash (cadmium, steel, lead), CO_2 and SO_2. Consumption of coal and oil is increasing all over the world. The increased number of vehicles also increases the carbon monoxide gas in the atmosphere due to the consumption of oil. Volcanoes also increase the amount of gases such as SO_2 and CO_2 in the atmosphere. These gases, which cause air pollution, react with the water in the atmosphere (H_2O). The result is acidic compounds such as H_2SO_4 (sulfuric acid), HNO_3 and HCO_3 (carbonic acid) as the reactions are given in Equations 1and 2, respectively. Nitric oxide (NO), which also increases the natural acidity of rainwater, is formed during lightning storms by the reaction of nitrogen and oxygen. In addition to that, high-temperature air combustion occurs in car engines and power plants produces large amounts of NO gas. In air, NO is oxidized to nitrogen dioxide (NO_2) and reacts with water to give nitric acid (HNO_3) (Equation 3). This type of gas falls on the earth in the form of rain, snow or fog with acidic properties and is called as acid rain.

$H_2O + SO_2 \longrightarrow H_2SO_4$ ……………………(Eqn 3.1)

$H_2O + CO_2 \longrightarrow H_2CO_3 \longrightarrow H^+ + HC$…(Eqn 3.2)

$H_2O + 3NO_2 \longrightarrow 2HNO_3 + NO$…………….(Eqn 3.3)

Acid deposition also includes the dry deposition of acidic particles and gases, which can affect landscapes during dry periods. The damage of acid rain is not limited to the forests, but it affects the living beings as well as the railways, buildings, bridges and historical remains. The CO_2 emissions leading to the atmospheric greenhouse effect as a result of the fossil fuel combustion reaction reached 0.6 billion tonnes/year in 1990, a significant increase especially in the last 40 years, reaching 5.5 billion tonnes/year in 1998.

Air pollution has an adverse effect on the climate by preventing the rays reaching to the places and spreading to the atmosphere. The acid rain causes chlorophyll breakdown in the leaves and causes the plant to yellow and dry. As is known, plants consume CO_2 during photosynthesis. Acid rain is drying up the vegetation and on the other hand it is setting the environment for the increase of the amount of CO_2 in the atmosphere.

3.5.1 Environmental effects of acid rain

Atmospheric pollutants are easily moved by wind currents. Therefore acid rain can affect very wide region even far from where pollutants are generated (see Figure 3.6). Acid rain is a growing environmental problem worldwide since it triggers a number of inorganic and biochemical reactions with deteriorius environmental effects. Acid rain is harmful to the whole environment, but the forests and agricultural areas are the most affected ones. These rains wash away elements important to plant growth such as magnesium and calcium in the soil structure and cause them to move deeply. As a result, trees and other plants can not benefit from the earth as much as they could. The loss of these minerals from the soil can kill trees and damage crops. It also causes the dissolution of the aluminum in the soil and prevents the tree roots from benefiting from the nutrients.

Acid rains cause the acidification of the cytoplasm, which leads to water balance in the leaves, entering from the stomata of the leaves. In leafy vegetables such as trees and spinach, the SO_2 closes the leaf surface in a plastic cover and prevents photosynthesis. As a result of this, water is lost and the leaf will soon die. In addition, the upper parts of the tree that are weakened by time and weakened by the leaves can not make the wind curtain and can be transferred from the wind. Thus, the green shoots of the trees do not grow and dry, their leaves spill, they do not give flowers and fruits. As the acid rain falling on the soil breaks the pH balance of the soil, the soil microorganisms are negatively affected from this situation and therefore they can not sustain their activities and thus they can not survive (Kızıloğlu T., 1995).

Acid rains fall into the ponds and rivers, disturb the acid balance in the water and affect the fish. In the acidic environment fish cannot live anymore. Influence of fish on this situation also affects us through the food chain.

Acid rain penetrates underground, surface and drinking waters, interacts with soil heavy metals and reacts to fish and plants. As a result of feeding with these foods, diseases such as goitre, ulcer, chronic bronchitis, asthma and emphysema occur in the human body due to the storage of acid substances (Kızıloğlu T., 1995).

Figure 3.6. Effect of acid rain on Great Smoky Mountains' Forest https://www.google.com.tr/search?q=Effect+of+acid+rain+on+Great+Smoky+Mountains

Acid rain causes pollution of our drinking water sources. If a small lake with drinking water is high and the acid rain falls, the ascending acid ratio increases and it becomes non-drinkable. Therefore, the environmental damages of acid rain should not be ignored, as these rains may cause the depletion of clean, drinkable water resources in the future.

Harmful gases that lead to acid rain cause various respiratory system diseases because they are in the air we breathe. If the rainy acid rains come into contact with the skin, it can cause discomfort such as skin cancer. Sulfate in the air is taken by respiration and causes various diseases such as bronchitis, asthma, cancer.

3.5.2 Effect of acid rain on stone buildings and monuments

Acid rains have abrasive properties. Buildings, sculptures and even historical artifacts in the surrounding area are destroyed due to erosion when they come into contact with acid rain. If the acid content in the acid rain is high, even the hardest rocks can be eroded. Stone works such as marble, lime and granite, which are forms of calcium carbonate, are used in the construction of historical works. Marble and limestone both consist of calcium carbonate ($CaCO_3$) differing only in their crystalline structure. Historical works were made of stones such as marble, limestone and calcareous sandstone. Although these are recognized as highly durable materials, buildings and outdoor monuments made of marble and limestone are now being gradually eroded away by acid rain. Since the sand particles in the sandstone coexist with a calcareous material, it is observed that the sand particles are poured over time due to acid rain and the effect of air pollutants.

A chemical reaction (Equation 4) between calcium carbonate and sulfuric acid which is the primary component of acid rain results in the dissolution of $CaCO_3$ to give aqueous ions. These ions are washed away in the water flow (www.chemistry.wustl.edu)

$CaCO_3 + H_2SO_4 \longrightarrow Ca + SO_4 + H_2O + CO_2$…...(Eqn 3.4)

The pH of the rainfall, the duration of precipitation and the temperature of the environment are also important when historical works are affected by acid rain.

References

IPCC (2007), Climate Change 2007: Synthesis report. Intergovernmental Panel on Climate Change, 4th Assessment Report, ISBN 978-92-9169-143-2.

Kızıloğlu,T. (1995). Toprak Mikrobiyolojisi. Atatürk Üniversitesi Ziraat Fakültesi, Yay. no: 180, Erzurum (in Turkish).

Web page (2017) retrieved from http://www.electricaleasy.com/2015/08/thermal-power-plant.html

Web page (2017) retrieved from www.britannica.com

Web page (2017) retrieved from www.qa-international. com, created and produced by QA International

Web page (2017) retrieved from www.chemistry.wustl.edu

Web page (2017) retrieved from https://www.google.com.tr/search?q=ozone+destruction+mechanism

Web page (2017) retrieved from https://www.google.com.tr/search?q=Effect+of+acid+rain+on+Great+Smoky+Mountains

CHAPTER 4

ECOLOGICAL AND ENVIRONMENTAL DIMENSIONS OF NUCLEAR POWER PLANTS

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Abstract: Nowadays, increasing energy demands make countries use fossil fuels because they are cheap and easily available. However, greenhouse gases (especially CO_2 emissions) caused by fossil fuels have sped up climate change. Therefore, as an alternative energy source the number of nuclear power reactors (NPR) has increased in the last years. Nuclear energy is having a revival as a potential alternate for electric power generation as there has been an increased concern about global warming. However, there have been approximately 100 of nuclear accidents in the last 60 years with some of them having serious impact on the environment. Along this line, nuclear power plants need to be evaluated with respect to their ecological impact. In this chapter; advantages and disadvantages of NPRs are given briefly. Ecological risks of all steps (from cradle to grave) are discussed in terms of; uranium mining, enrichment, nuclear fuel cycle; processes in the reactor, disposal of radioactive waste, dismantling of the

reactor. “Energy efficiency, climate change, public health, ecosystems, biodiversity, future generations and public participation” are all taken as the basic criteria to evaluate nuclear energy, while also taking into consideration the economic, political and social aspects.

Learning objectives:

At the end of this chapter, Students will have an idea on:

- Advantages of NPRs,
- Disadvantages of NPRs,
- Riskful aspects of NPRs,
- Evaluation of NPRs from Ecological Aspects (in terms of climate change, the quantity of energy obtained, economical efficiency, ecosystem, bio-diversity, safety, community health, rights of future generations, and participation of community)

4.1. Introduction

Nowadays, majority of energy being supplied is based on fossil fuels. Fossil resources are expected to disappear in the near future (nearly 150 years) and as the greenhouse gases coming out of them cause climate change, there is a need to search for alternative energy sources. Although people's attention focus more on renewable energy sources, the energy in this area is not sustainable. As they cannot be stored or they are not sufficient enough and as these constitute restrictions, “nuclear energy” has stayed in the agenda as being a strong alternative to fossil fuels.

Nuclear means being related with nucleus. Nuclear energy is the energy that comes out as the chain reaction of atomic particles. Energy occurs as a result of two basic reactions such as **fusion** and **fission.** The energy that comes out as a result of fission of heavy radioactive substances (**Uranium**), due to the neutron bombardment or during the fusion of light radioactive substances, is significantly big. Fundamental principle that is used at the plants to derive nuclear energy is via fission reaction specifically uranium (see Figure 4.1).

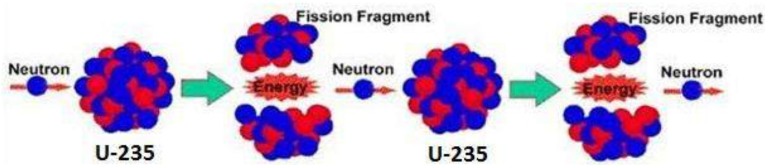

Figure 4.1. Fission reaction and chain reactions (http://www.electricalport.com/technical-pole-section/is nuclear alternative-what is nuclear energy -/4173#ad-image-0)

This term was first heard during 2nd World War. Where, the beginning of studies began as relating to the bombs that were dropped onto the city of Hiroshima in Japan on the 6th of August, 1945 and onto the city of Nagasaki on the 9th of August, 1945, Rutherford, Hans, Strassman, Oppenheimer and Einstein were the first scientists who studied on this energy source. (Karabulut Y., 1999) Nowadays, 10.9 % of the world's electricity is produced by nuclear plants. According to the "Power Reactor Information (PRIS) data" at International Atom Energy Agency, 441 nuclear reactors plants are being operated currently in 31 countries. (As of 15th of November, 2015).

However, in 25 years following Chernobyl nuclear accident, nuclear power plant construction declined while the global demand for electricity more than doubled. As a result, nuclear's share of the total electricity supplies peaked at a shameful number of 18% in 1996 before falling to 11% by 2014 (see Figure 4.2)(https://www.carbonbrief.org/mapped-the-worlds-nuclear-power-plants)

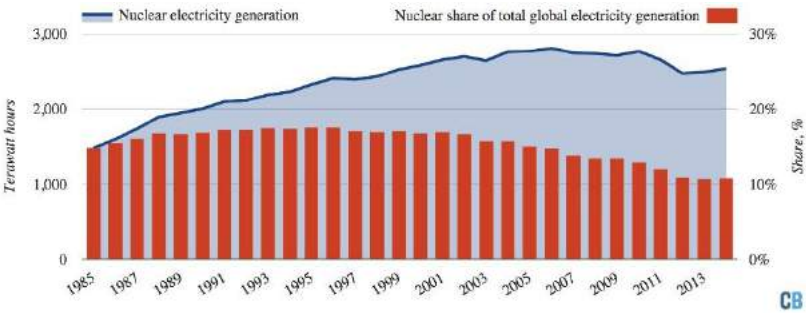

Figure 4.2. Global nuclear electricity generation (blue area, left axis) and nuclear's share of total world power generation (red bars, right axis). (BP Statistical Review of World Energy 2015 and Carbon Brief analysis. Chart by Carbon Brief)

Advantages of nuclear energy

-Not using fossil fuels and non-formation of greenhouse gas emissions,

-Reduction in dependency on fossil fuels, the resource of which is being used rapidly,

-Being more efficient as compared to renewable energy sources,

-Provides strategic and political power for countries (It being used for military purposes besides as energy source)

-It being more stable from economical aspect with respect to the prices changes in fossil fuels

Disadvantages of nuclear energy

-High risk of radiation in case of accidents causes negative impacts on living creatures including humans for generations,

-Many issues are experienced when disposing of radioactive waste

-It being an expensive energy source,

-It requires external dependence with regards to sources and technology,

-Negative impact on the environment in cases where the relevant location is chosen in a wrong way,

-It requires a long period of time to start operating and its operational period is short

In fact, nuclear energy is a **political** choice and the real debate occurs in the political arena. But due to human tragedies that have occurred as a result of nuclear disasters; it also has aspects of **ethics** and **conscience**. (Caldicott H., 2014) Therefore, it is important and even necessary to evaluate the advantages and disadvantages of nuclear energy by looking at it as a relationship between humans and nature and by making investigation from **ecological** aspect and therefore having a more holistic point of view.

For this purpose, first of all the research looked at the various stages of the energy sources such as uranium mining, uranium enrichment, operation of reactor, disposal of wastes, and disassembly of the plant.

"**Risky aspects of nuclear power plants"** have been investigated and furthermore, the topics of "**costs**" and "**security**" have been questioned again and again, while ecological evaluations were conducted regarding below particulars;

a) Energy efficiency

b) Climate change

c) Human health

d) Ecosystems and bio-diversity

e) Future generations

f) Public participation

These evaluations comply with the articles below that are required reading in order to meet the investigation of "production of energy policies which are more rational" as they are specified in the Extern-E Report (1995) that was prepared by European Committee:

- Risk analysis with regards to the disposal and recycling of used nuclear wastes
- Comparison of carbon dioxide emissions

- Calculation of nuclear energy risk factors so as to be able to create a radiological risk evaluation and other economical foresights.

4.2. Riskful aspects of nuclear power plants

Just how safe are nuclear power plants are still one of the mostly hotly debated topics among the scientists in the world. In order to approach the event from a holistic point of view, while making ecological evaluation of these plants, all the stages should be considered and all risks should be evaluated. For this reason, discussions will be held relating to processing and embedding the wastes coming out as a result of uranium exploration, storage of used fuel, processing the wastes or reusing the used fuel by processing it again, risk factors relating to the stages when the reactor has completed its life cycle and when it has to be disassembled, and the plants probable impact on the environment (being ecological).

4.2.1. Uranium mining

In order to convert uranium from raw material, rocks containing uranium are taken and they are made subject to various physical and chemical processes and a solution is obtained which contains uranium element. Afterwards this solution is precipitated in the form of uranates. During these processes, a small quantity of gas emerges via exhaust from the machines and due to this situation there is “greenhouse effect”. In addition, there is small quantity of radioactivity dispersion.

4.2.2. Uranium enrichment

After uranium ores are extracted, they are made subject of an "enrichment" process so that they can be used in the plant. But there is a risk here such that production of "nuclear weapons" is possible during the process of enrichment. This can give rise to a situation where some countries become interested in nuclear armament and proliferation of nuclear weapons can take place. In case nuclear weapons are used, radioactive particles form and spread not only in that region but in a much wider geography area and they keep on existing for many years afterwards.

4.2.3. Operation of a reactor

All of the nuclear plants in the world generally work on the basis of nuclear fission. The heat that forms as a result of this reaction is then transformed into energy. The water in the system is boiled with this heat and steam is obtained. The steam that is obtained from this is sent into a turbine under great pressure. Then the turbine causes the electric generator to turn and as it goes through the turning process, energy is derived. All of these processes take place in a system that comprises of many mechanical parts (around 50.000) all of which have the probability to breakdown. This is a risk factor which can increase radiation leakage. (Kurokawa G. et al, 2011). For example, breakdown of cooling systems and overheating that comes as a result of this (nucleus fusion) is one of the most serious threats that could cause radiation dispersion.

In various discussions regarding nuclear power plants, “accident risk”, is considered to be low due to high technology and the safety measures that are taken. But it does specify that in case of an accident, its impact could be very big. (Erdöşemeci F., 2014). When nuclear plant accidents occur they are graded according to a scale as per their outcomes.

They are graded from 1 (least influential) to 7 (most influential and “major” accidents) (IAEA and OECD/NEA, 2008). However, even if it is stated that “risk is low”, in the 60 year history of nuclear plants there have been 99 nuclear plant accidents 2 of them have been “major accidents” reaching level 7; 2 of them were “serious accidents” with level 6; 1 of them was “offside risk (accidents comprising risks outside the facility) that were level 5. (Kurokawa et al, 2011: 13). The three most notorious “nucleus fusion” accident were a largest scale accident at Fukushima in Japan in year 2011 and in Chernobyl in Ukraine in year 1986, and Three Mile Island in Pennsylvania in year 1979. Also, between the years of 1952-2011, nuclear fusion accidents on large scale took place in 4 nuclear plants and smaller scale fusions took place in 10 reactors. Plus on 8 submarines owned by Soviet army (1961-1985), nuclear fusion and radiation leakage took place. Japanese government closed 50 out of 54 reactors after the accident took place in Fukushima. (But these reactors are still listed as being operated with the assumption that they will be opened in the near future and they are shown with this situation the IAEA lists). Similarly, after the accident that took place in Fukushima, Germany closed 8 of their 18 reactors and they announced that the remaining ones will be closed by 2022. After the accident in Chernobyl in year 1986, Italy closed 4 nuclear reactors in their country, while Austria closed their newly established plant without even using it.

4.2.4. Disposal of wastes

Radioactive waste can be classified as low, medium, or high grade depending on the radioactivity level they have. (IAEA, 1995). The waste that occurs in nuclear power reactors is considered ‘high level waste’ and they make up 3% of all of the radioactive wastes in volume and 95% with respect to radioactivity. In addition, their half-lives are also very long. (For example half-life of Pu 239 is 24 065 years). Nuclear waste management could be realized in two stages;

a) Reducing its volume and radioactivity level by reprocessing and then storing them: Reprocessing is a highly expensive technology and it also a security threat. For example, a 1GW reactor can produce 240 kg of plutonium and this quantity is sufficient for 20 nuclear weapons.

At some nuclear reactors spent fuel is kept on site, above ground, in a system that is similar to the one shown here in Figure 4.3. Once the spent fuel has cooled, it is loaded into special canisters. Each canister is designed to hold approximately 2-6 dozen spent fuel assemblies, depending on the type of assembly. Water and air are removed. The canister is filled with inert gas, and sealed (welded or bolted shut).

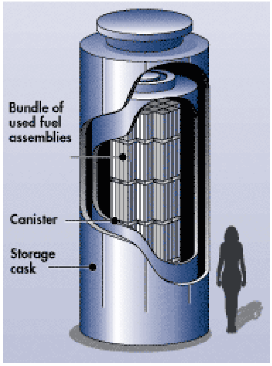

Figure 4.3. Vertical canisters with concrete or steel structures (https://www.nrc.gov/waste/spent-fuel-storage/diagram-typical-dry-cask-system.html)

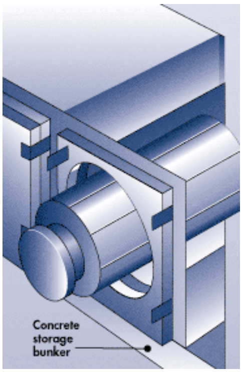

Figure 4.4. Horizontal canisters (https://www.nrc.gov/waste/spent-fuel-storage/diagram-typical-dry-cask-system.html)

Some canisters are designed to be stored horizontally in above-ground concrete bunkers, each of which is about the size of a one-car garage (see Figure 4.4).

b) Final storage: In countries where there are nuclear power plants, certain national and international policies are available for the final storage of radioactive waste that is created as a result of production.

The important topic regarding the disposal of nuclear wastes is that there isn’t any final storage facility in the world which can accept “high level waste” in the operational stage because there is an obligation that it must be away from risk for at least 250.000 years. (Altın S. and Kaptan H.Y., 2006). Throughout the world, the final waste facilities that can accept “high level of waste” are being closed. One of the last ones to close be the facility is situated on Yucca Mountain in the Nevada in USA. But in year 2009 the storage process was stopped in this region and a committee has been established to create alternative solution and as a temporary solution to this problem, the condition for storing the radioactive wastes within the plant for 20 years has been added to the contracts relating to nuclear power plants. Nowadays, high level radioactive wastes is being stored in Carlsbad-New Mexico, while low level radioactive wastes is stored in Barnwell-South Carolina, Richland-Washington, Clive-Utah, and OakRidge-Tennesseeregions. (World Nuclear Association, 2014).

All of these reveals that finding a safe place to embed nuclear waste so that it is isolated as not to cause any leakages still remain a very important and unsolved problem worldwide. For this reason, this risk is being transferred to the future generations.

In a world where it is very difficult to find a place for nuclear waste, another problem has appeared and it is related to “exportation of dangerous wastes”. Developed countries deliver their radioactive wastes to 3rd world countries. The outcome of the wastes that is sent to these countries is uncertain, while they continue being dangerous both for that country and for the other countries in an indirect way. (Ecosystem makes up a whole).

4.2.5. Dismantling

Nuclear power plants are generally designed to be operated for 30-40 years. This lifespan could be prolonged to maximum 60 years through appropriate management programs and new technological developments. The cost of dismantling a nuclear plant that has completed its lifespan can reach up very high amounts and the risk of radiation leakage also can appear. When the economic lifespan of the plant is completed, the cost of disassembling its parts and the disposing of it can make up 10-15% of total cost. (For example, the cost of dismantling a standard plant that is 1200 MW in Germany and to convert it into a green area was around 400 million Euros which made up 20% of first investment cost. In France, cost of dismantling a nuclear plant of 900 MWe had a 15% of first investment cost. (World Nuclear Association, 2014). The particular thing that needs to be emphasized here is that this cost is first reflected onto the enterprise and then it is indirectly reflected onto the community by the enterprise.

4.2.6. Cost:

The cost of a nuclear energy system has always been higher than shown in the figures by the politicians and researchers till now and “the cost it has on the impact on the community and environment” has neither been considered as part of the calculations or it has been neglected. Consumption costs of a nuclear plant that has a very long construction period is such that 60% of the costs are related with production, 20% of them are related to fuel, whereas 20% of them are related to maintenance and repair work. Within the cost of electricity generated by a plant through its lifespan, particulars such as first investment, fuel, maintenance and repair, waste disposal, and deactivating it as it completes its lifespan come out to the forefront. However, the below stated costs remain hidden and are not considered as part of the calculation;

- Costs regarding nuclear power being compared with other energy systems as part of Research and Development studies,
- Cost of problems that can arise in the long term as part of nuclear waste and deactivation,
- Loss in the value of land where the power plant will be established and the loss in tourism revenue,
- The cost that radiation can create as a result of a nuclear accident on the people, community, and the natural environment. (For example the expenses for the treatment of diseases relating to radiation, loss of

labor force, decline in production, the damage it does to the agricultural lands and ecosystems, and polluting drinkable water sources

In addition to these, existence of particulars such as first investment cost that is high, long construction period (10-12 years), while having a very short plant life (50-60 years) should not be forgotten as they bear negative features. When the high costs and probability of being subjected to radiation for generations to come is considered, it is required people to question the efficiency and reliability of an energy that has such a short lifespan. (Extern-E, 1995).

4.2.7. Nuclear plants as being a target in wars and terrorism:

If war breaks out between the two states, they can choose nuclear power plants (if they are available) as target to strike since it can create such negative effects. Furthermore, in case a security deficit occurs, nuclear power plants can become open targets for national and international terrorism and sabotage.

As it was explained in the section regarding the advantages of nuclear energy, nuclear reactors don’t produce air pollution or carbon dioxide as they operate unlike fossil fuel plants. However, despite this the process which involves mining and purification of uranium ore and preparing it to become reactor fuel requires high quantity of energy. Nuclear energy plants also require big quantities of metal and concrete. If fossil fuels are being used for the mining and purification of uranium ore or if fossil fuels are used when nuclear plants are established, it is hard to say that it does not cause climate changes as a result of the emissions of nuclear power plants. Because of the carbon footprint it leaves behind to be built.

4.3. Evaluation of nuclear power plants from ecological aspects

On one side there is the global warming problem and the impact which is being felt by people and the environment and on the other side is the increasing demand for energy; therefore, the big risks that the nuclear power plants have (although it is asserted that they are less) are part of this dilemma and it is needed to be discussed and decide which values are more important for people with respect to environmental ethics or the need for energy. From this point forth, Table 4.1 has been formed and values such as **climate change, the quantity of energy obtained, economical efficiency, ecosystem, bio-diversity, safety, community health, rights of future generations, and participation of community** have been evaluated from ethical aspect and have been investigated on how these would influence the ecosystems. (By also emphasizing on political, economic and sociological dimensions).

Table 4.1: Evaluation of features of nuclear power plants from ecological aspect

Ecological Universe	Evaluation from ecological point of view
Climate change	As there is no greenhouse gas emission, it does not contribute to climate change and the existing plants provide %17 reduction in greenhouse gas emissions. However, there is bigger demand for energy in the world and in order to meet this demand, more nuclear plants are needed and each one of them creates risk for ecosystems. Even though nuclear plants would continue being established, as long as other important components (exhaust gases, deforestation and loss of commons). are not eliminated it does not truly help
Quantity of energy	Energy efficiency is high but existing risk factors should be kept in mind.
Economic efficiency	It causes ecological values to be pushed aside and only considered to be of secondary importance and the damage it can cause. (conflict between ecological

	and economical aspects)
Ecosystem and Bio-diversity	Ecosystem services could be interrupted. (Forest, water resources, food resources, animal breeding etc.) In case of an accident; -Dispersion of radioactive particulars through the air, wind and water can be carried to different regions and different continents -Accumulation of radioactivity in food chain -Permanent genetic deformation in living species including humans
Wastes	-Level of radiation in waste is significantly high and radioactivity remains for long years (hundreds of thousands of years). -Since isolation of waste has a high level of radioactivity it can be very expensive, and the safety deficiency could hurt the ecosystem. -There is a safety deficiency as it is difficult to find a secure place to store the waste where it will not hurt ecosystems and/or living creatures. (To find

	impermeable places for hundreds of thousands of years). -Furthermore, it is possible for places that are considered to be safe today to become risky in the future due to earthquakes and tectonic movements.
Safety	-“Human mistakes” could arise even in new generation nuclear plants that are considered to be very safe. -Big natural disasters can even threaten the most secure nuclear plants
Community health	It is important for humans to live in harmony with nature and in a healthy way, so as to be part of the earth and its ecosystem. -It is a requirement for the human genes not to be influenced by radioactivity so as not to be damaged
Future generations	-The risk of genetic mutations and the disruption of ecosystem cannot be avoided from ecological point of view as these could have impact on the future generations of both the living species and the humans!
Public	-Especially the plants that are established at the regions where local communities

Participation	reside or in the nearby regions can bear the risk of disrupting the areas and also disrupting the traditional (ecological) life style. -In case of an accident, traditional life style of communities and their living areas such as soil and water environment can come under threat due to disruptions cause by radiation.

While decisions are being taken to establish and operate nuclear power plants, especially in **developing countries**, it is highly important to have a look at the benefit-cost analysis with scientific evidence and to investigate potential impact (from ecological aspect) of this technology. Because it would be lot more difficult for these countries which have fragile economies to regain strength in case of occurrence of a nuclear accident.

The biggest advantage that those defending nuclear power plants have is that the plants have a positive contribution to global climate change and that they are energy efficient. Besides, these plants are becoming more efficient with the advances in technology and that the risk of accidents is being significantly lowered. (Gamson W.A. and Modigliani A., 1989) (Yıldırım M. and Örnek İ., 2007). When the heavy pressure of climate change on living species and the ecosystems is considered, these features seem to be positive. According to the study conducted by Pacala and Socolow (2004), nuclear energy could be an option to reduce emission of greenhouse gas in order to fix the global carbon dioxide emission by year 2050 (not to reduce it); there is a need for nuclear power plants that generate energy of 700 GW. However, according to Caldicott H., (2014) although there is a plan to replace 10% of fossil based energy via nuclear energy worldwide as of 2050, it also revealed that nearly 100 nuclear power plants need to be established by then. This means that during the coming 36 years, 28 new nuclear plants would need to be opened and operating. If the target is to reduce the carbon dioxide emission by half by using nuclear energy instead of keep using the carbon dioxide emission at the current level it would require the world to increase the number of reactors to 1400. However, this amount of nuclear power plants would cause new wastes to be created and thousand tons of plutonium would be produced (as being raw material for nuclear weapons).

83 % of the electrical energy that is used during the enrichment stage of the fuel that is to be used in a nuclear power plant is met by energy sources that are not nuclear. When the energy required to extract and to carry the uranium from the mine is also considered, this ratio gets even higher. It means that while the nuclear power plant is being build it requires the use of carbon and other energy sources. In addition to this, as long as other factors that are causing global climate change are not eliminated (especially exhaust gases, fires occurring at forests and grass areas etc.), increasing number of nuclear power plants will not create a solution to this

problem. On the contrary, it will create more serious problems.

Another missing point in the discussions regarding nuclear plants (although various physical factors are considered while decisions are taken with regards to the disposal of radioactive wastes and while risk analysis and modelling are realized) is that the "social" dimension is not considered sufficiently enough.

References:

Altın, S., & Kaptan, H.Y. (2006). Radyoaktif atıkların oluşumu, etkileri ve yönetimi. In Proceedings of 12. Mühendislik Dekanlar Konseyi 2.Ulusal Mühendislik Kongresi, Zonguldak.

Caldicott, H. (2014). Nuclear power is not the answer. New York, U.S.A.: The New Press.

Dreicer, M., Tort, V., & Manen, P. (1995). ExternE: Externalities of energy Vol 5 Nuclear (EUR--16524-EN). International Atomic Energy Agency (IAEA).

Erdöşemeci, F. (2014). Nükleer güç santrallerinin çevre etiği açısından irdelenmesi (Unpublished M.Sc. Thesis). Gazi University, Ankara.

Gamson, W. & Modigliani, A. (1989). Media discourse and public opinion on nuclear power: A constructionist approach. American Journal of Sociology. 95(1), 1-37.

IAEA (1995). The Environmental and Ethical Basis of Geological Disposal of Long-Lived Radioactive Wastes" Annex I.

IAEA and OECD/NEA (2008). INES (The International Nuclear and Radiological Event Scale) User's Manuel.

Karabulut, Y. (1999). Enerji kaynakları, Ankara, Turkey: Ankara Üniversitesi Basımevi.

Kurokawa, G., S. Iyengar, D. Macer, K. Uejima, N. Chaipraditkul, A. Dorjderem, S. Gardini, C. Liuying, C. Kuppuswamy, J. Rajan and S. Rao (2011). Ethics of Nuclear Energy Technology (ECCAP WG12 Report). Ethics and Climate Change in Asia and Pacific (ECCAP) Project, Draft 6.

Pacala, S. & Socolow, R. (2004). Stabilization wedges: solving the climate problem fort he next 50 years with current technologies. Science. 305(5686), 968-972.

Yıldırım, M., & Örnek, İ. (2007). Ultimate choice for energy: The nuclear energy. Gaziantep University Journal of Social Sciences. 6(1), 32-44.

Web page (2017), retrieved from http://www.electricalport.com/technical-pole-section/is nuclear alternative-what is nuclear energy -/4173#ad-image-0.

Web page (2017), retrieved from https://www.carbonbrief.org/mapped-the-worlds-nuclear-power-plants

Web page (2017), retrieved from https://www.nrc.gov/waste/spent-fuel-storage/diagram-typical-dry-cask-system.html)

Web page (2017), retrieved from http://www.world-nuclear.org/.

CHAPTER 5

SOLAR ENERGYSYSTEMS AND ENVIRONMENTAL EFFECTS

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Abstract: Solar energy is the thermal energy emitted by the sun through nuclear fission and fusion of hydrogen atoms in the sun's core and on its surface. The use of solar energy can be classified as direct (e.g. solar thermal or photovoltaics) or indirect (e.g. wind, hydro or bioenergy). This chapter will only cover direct use: solar thermal and solar photovoltaics technologies. The first part of the chapter focuses on technological aspects and the components of solar energy applications. In comparison to conventional power plants energy produced from renewable energy technology have less greenhouse gas emissions and other environmental impacts. However, there are some environmental impacts along the value chains or solar energy projects. Some of them are described in the second part of this chapter.

Learning Objectives

- Readers will be informed about various solar energy technologies
- Readers will be able to evaluate the environmental impacts of solar energy technologies along its lifecycle

5.1. Technological aspects of energy generation in solar energy systems

Solar energy is the thermal energy emitted by the sun through nuclear fission and fusion of hydrogen atoms in the sun's core and on its surface. The sun provides the earth with a tremendous amount of energy which makes life as we know it possible. This incoming energy is reflected, diffused, absorbed and reradiated by particles and clusters of molecules in the atmosphere and on the surface of the earth and the oceans. This in turn causes winds, oceanic currents, evaporation, condensation (rain), and regulation of the temperature of the earth's surface. Plants and trees convert light energy into chemical energy via the process of photosynthesis, creating biomass. This falls into the category of indirect use of solar energy.

The use of solar energy can be classified as direct (e.g. solar thermal or photovoltaics) or indirect (e.g. wind, hydro or bioenergy). This chapter will only cover direct use.

Technologies for direct use of solar energy are:

Solar thermal systems use solar energy to produce hot water for a wide range of consumers such as private households, hotels, hospitals, or for industrial processes. They can also be used in space heating or cooling applications.

Concentrated Solar Power (CSP) plants concentrate solar energy via mirrors to generate high temperatures which are used to produce steam to drive steam turbines to generate electricity. It is a solar thermal technology for generation of electricity.

Photovoltaic (PV) systems convert solar energy directly into electricity by means of the photoelectric effect.

5.1.1.Solar thermal

The conversion of solar radiation into heat, or thermal energy, is called "solar thermal". Solar thermal has the highest efficiency of all the different types of solar energy. This thermal energy can be used for domestic hot water (DHW) provision, for space heating, for thermal processes (process heat), or even for cooling.

5.1.1.1. Components of a solar thermal system

Absorber

The heart of every solar thermal system is the absorber. It is made from a highly conductive metal sheet, preferably copper. For economic reasons aluminium is increasingly being used as it costs less than copper and is also a good conductor. The surface is coated with the selective, radiation absorbing layer that converts the light into heat.

This heat then conducts through the metal to channels in which a heat transfer fluid is circulated. The heat is transferred to the fluid via convection and the hot fluid is transported either to where it is used or where it can be stored. The heat transfer fluid is generally water or a mix of water and antifreeze, however air can also be used (as in air collectors) (see Figure 5.1).

Collector

If higher temperatures are required, such as for DHW (domestic hot water) provision, space heating or process heat, then the absorber must be covered and insulated to hinder heat loss.

There are two types of collector, flat plate and evacuated tube. In the flat plate collector, a glass cover is fitted a few centimetres above the absorber which allows the solar radiation through but reduces convection heat losses (greenhouse effect). Thus, light penetrates through the glass cover and is converted to heat in the absorber. Mineral fibre or foam insulation is fitted to the back and sides of the collector to minimise conduction and convection losses and trap the heat inside.

Evacuated tube collectors have a high efficiency due to the good insulating properties of the vacuum within the tubes. A simple type of evacuated tube comprises an evacuated glass tube into which an absorber strip with a selective coating is inserted. A coaxial pipe (a pipe within a pipe) runs along the length of the underside of the absorber strip. Inside the coaxial absorber pipe, the heat transfer fluid flows down the inner pipe and back up the outer pipe where it picks up the heat from the absorber strip. The glass tube is sealed with a metal lid. The coaxial absorber pipe penetrates this lid and opens into a header pipe. This is a direct flow collector.

Thermal stores

There are times when solar irradiation levels are not high enough to meet demand, for example, at night and in the winter. At other times, there is too much solar irradiation. Both these situations make it desirable to have a thermal store in the solar thermal system. Water is usually used as the thermal store medium for several reasons: it has a very high specific heat capacity, it does not present a health risk and it is available almost everywhere.

Domestic hot water (DHW) stores are used for hot water provision. They contain potable water that is drawn off at, e.g. taps or showers.

Stores for space heating or process heat applications are called buffer stores. These contain process water that circulates around a closed circuit and is not consumed.

Combi stores are buffer stores with an integrated DHW store (tank in tank) or integrated DHW heating coil.

The store itself is made from steel, enamelled steel, stainless steel or copper depending on the application. Unpressurised (or open vented) cylinders are increasingly being manufactured from plastic, plastic film or glass fibre reinforced plastic.

Thermal insulation around the store is very important to reduce thermal losses as far as possible and thus to increase the overall system efficiency.

Pump

In forced circulation systems, pumps are used to move the heat transfer fluid around the system. The same type of pump can be used as in a conventional heating system. The pump specification for solar thermal systems is however somewhat different. In conventional heating systems, a high flow rate, low pressure loss pump is required. For solar thermal systems a high-pressure loss, low flow rate pump is required, i.e. a pump with a different performance curve.

Expansion vessel

In sealed systems, an expansion vessel takes up the fluid expansion that takes place due to changing fluid temperature. Expansion vessels for conventional heating systems can in principle be used in solar thermal systems. However, if antifreeze is being used then the expansion vessel membrane must be resilient to this. In addition, measures must be taken to avoid the membrane being exposed to high temperatures during periods of stagnation.

Other components

Fluid expands when it is heated and can produce high pressure. Therefore, a safety valve must be incorporated into a sealed system to release pressure in the event of system pressure rising to unsafe levels. Such a pressure increase can occur when, for example, another system component such as the expansion vessel fails. The safety valve is sized in the same way as in a conventional sealed system.

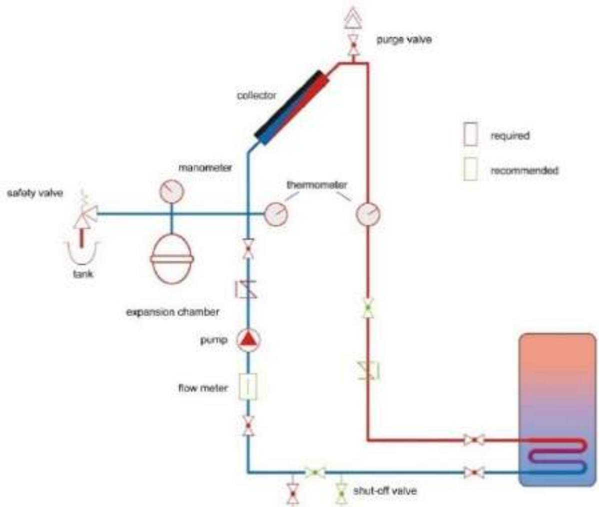

Figure 5.1. Solar thermal system components, forced circulation system (Source: RENAC)

5.1.2. Concentrated solar power (CSP)

Concentrated Solar Power (CSP) technology concentrates solar radiation to achieve high temperatures typically in the range 290 – 1000°C. This thermal energy is either used directly in process heat applications or converted to electricity via steam turbines.

CSP requires very high levels of direct solar radiation, therefore the geographical locations for implementation worldwide are limited. Parabolic trough, solar tower (or power tower), Linear Fresnel reflector, and parabolic dish are four of the main types of CSP found.

5.1.2.1. Components of a solar CSP

Parabolic trough collectors

Solar radiation is reflected from the parabolic trough onto an evacuated tube receiver running the length of the trough (see Figure 5.2). The parabolic troughs are installed around 8 m above ground level. They are aligned from north to south. The evacuated tube receiver contains a heat transfer fluid which is heated up by the concentrated solar radiation. The heat transfer fluid delivers heat to a heat exchanger in a conventional steam power plant. Water on the other side of the heat exchanger is converted to superheated steam which drives a steam turbine to generate electricity. Different heat transfer fluids are used depending on the application.

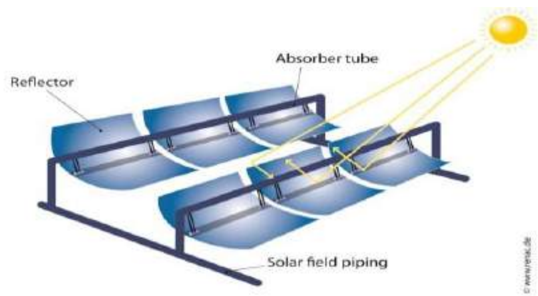

Figure 5.2. Scheme of a parabolic trough collector (Source: RENAC)

Solar tower (or power tower or central receiver)

Solar radiation is reflected from hundreds, or even thousands, of heliostats (large steel reflectors) onto a central receiver at the top of the solar tower. This technology is categorized as ‘point-focusing’. The heliostats are each equipped with a dual motor two-axis tracking system. The heliostats are arranged around the central receiver either in the surrounding field configuration (typically for larger plants with capacities of e.g. 100 MW) or in the north field configuration (typically for smaller plants with capacities of e.g. 20 MW) (see Figure 5.3).

The solar radiation reflected onto the tower’s central receiver converts water to superheated steam which is used to drive a steam turbine and generate electricity.

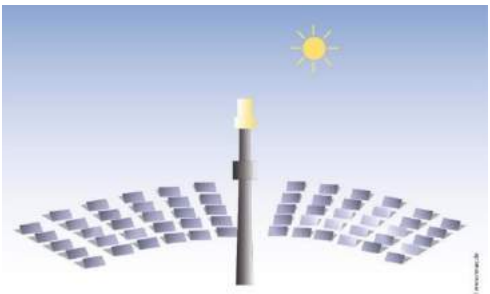

Figure 5.3. Operation of a solar tower (Source: RENAC)

Linear fresnel

Linear Fresnel is categorized as a ‘line-focusing’ technology. Linear Fresnel Reflectors (LFRs) approximate the shape of parabolic troughs with long, mirrored strips which reflect the solar radiation onto a downward-facing, fixed receiver tube running the length of the reflector (see Figure 5.4). The reflector strips track the sun from east to west while the receiver tube stays in a fixed position. A secondary reflector surrounding the receiver tube reflects any unfocused radiation back onto the tube.

LFR systems heat water running through the receivers directly to generate steam at around 270°C (Direct Steam Generation – DSG), thereby eliminating the need for synthetic heat transfer fluids and heat exchangers. This, along with the lower manufacturing and installation cost of the mirrors make LFR systems less expensive than parabolic trough systems.

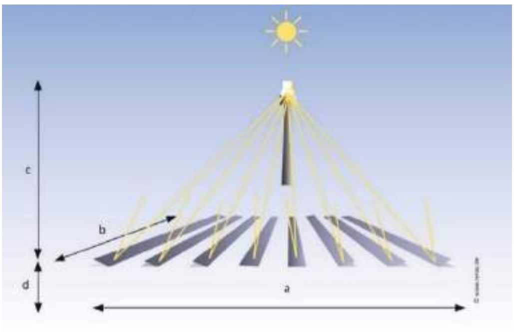

Figure 5.4. Operation of a Linear Fresnel collector (Source: RENAC)

Dish

The dish reflector concentrates solar radiation onto a receiver at the focal point of the dish ('point-focusing' technology). The receiver is heated to around 750°C and drives a small piston, Stirling engine or micro turbine attached to the receiver to generate electricity directly at the dish (see Figure 5.5). The dish tracks the sun throughout the day. Dish sizes typically range from 5-25kW. The high solar concentration and operating temperatures have allowed dish systems to achieve solar-to-electricity conversion efficiencies of up to 30%.

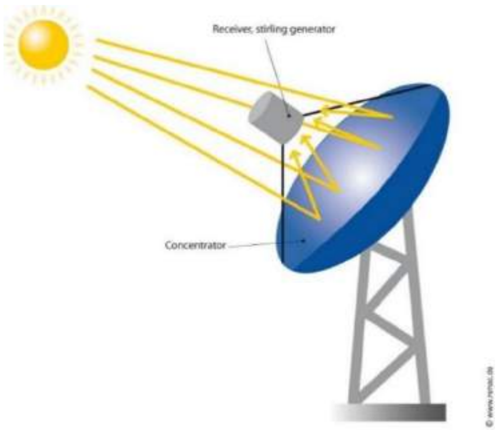

Figure 5.5. Operation of a dish collector. The dish tracks the sun throughout the day (Source: RENAC)

5.1.3. Solar PV

There are two basic system topologies for PV systems: grid-tied systems and off-grid systems. Grid-tied PV systems feed their power production into a centralized electricity grid. Grid-tied systems could be applied in large-scale (utility-scale) energy production with PV power plants and household or industry energy supply.

Off-grid PV systems can be applied in many areas where there is no grid connection, for example water pumping for irrigation or human consumption, solar Home Systems (SHS) for households in rural areas or developing countries, communication antennas and telemetry stations etc.

Figure 5. shows a basic scheme of some of the essential components in both off-grid and grid-tied systems.

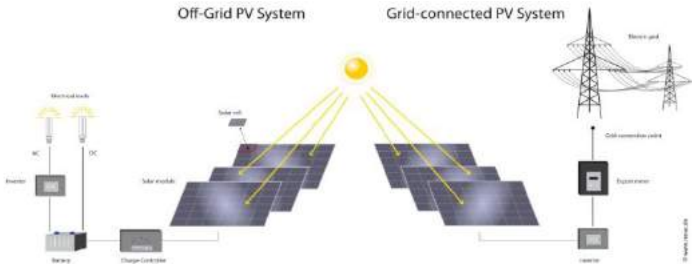

Figure 5.6. Overview of off-grid and grid-tied PV systems

Solar cells

Monocrystalline and multicrystalline c-Si cells are wafer-based with thicknesses varying in the 100 to 250 μm range and sizes from 4 to 6 inches. The wafers are gained from a silicon melt by different methods, condensed into blocks and then cut with a wire saw. Due to the need for very high purity, a lot of energy is consumed during the manufacturing process as high temperature processes are necessary in order to remove defects. The electrical contacts on both front- and back-sides are deposited by screen printing.

Thin-film solar cells (amorphous Si, cadmium telluride, copper indium gallium selenide solar cell [CIGS]) are commonly deposited on a piece of glass. The surface is then prepared with a laser and the electrical contacts are deposited. The energy consumed for thin-film fabrication is much lower than for c-Si solar cells because the deposition is a low temperature process. Furthermore, the fabrication process is therefore much faster and cheaper than that of c-Si, however the efficiencies of the technologies are lower than c-Si.

5.1.3.1. Main components of a solar PV systems

Solar modules

Solar modules are composed of a number of solar cells connected in series and parallel in order to obtain a desired final power output of the module. The number of solar cells in crystalline modules varies typically between 36 and 72 cells. The solar cells are electrically connected and sandwiched between two very thin transparent layers of vapor-proof encapsulation material (commonly made of Ethylene Vinyl Acetate or EVA), then placed on top of a reflective back sheet (commonly made from polyvinyl fluoride), and then sealed with a glass cover in an aluminium frame.

Inverters

Inverters transform direct current (DC) into alternating current (AC) and regulate voltage and frequency. There are mainly two types of inverters: Single- and three-phase inverters. Single-phase inverters deliver AC to one phase of a power transmission line, whereas three-phase inverters deliver AC to all three phases of a power transmission line. Small systems, typically below 5 kWp, usually use single-phase inverters because one line is sufficient to absorb the power delivered by a PV system.

5.2. Environmental impacts from solar energy systems

In comparison to conventional power plants energy produced from renewable energy technology (RET) have very less greenhouse gas (GHG) emissions. On the other hand, if we consider the whole life cycle of a RET, the impacts on environment cannot be overseen.

Figure 5.8 represents the inputs and outputs in the life cycle of the renewable energy projects.

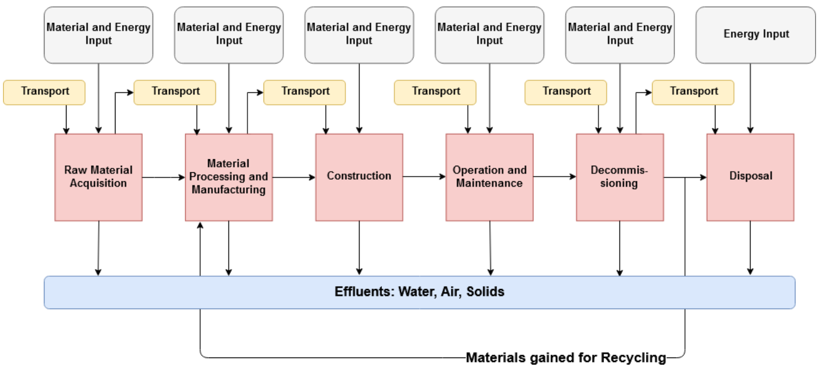

Figure 5.7. General life cycle of renewable energy technologies (Corona, Cerrajero, López, & San Miguel, 2016) (Fthenakis & Kim, 2011); own representation

A method used to determine the total environmental impact of a product during its entire life cycle is known as life cycle assessment (LCA). LCA is used as a tool in Environmental Impact Assessments (EIA) to represent the extent of environmental impacts.

An EIA is a study carried out to assess the potential environmental impacts from a proposal. In an EIA and LCA the impacts are categorized according to the nature and type of emissions. The categories may also vary depending on the country and institutions. In this chapter, the impacts are not categorized. General potential impacts and prevalent impacts from different literature are presented in chapter 5 and chapter 6.[1]

The first two phases in a life cycle are raw material acquisition and manufacturing. During the extraction of raw materials, series of impacts on environment are entailed. Different factor plays a role for the extent of the impacts. The factors could be the art of raw material which will be extracted, technology used for the extraction or ecology of the area. Similarly, during the material processing and manufacturing phase, different impacts occur with different extent depending on the nature of material.

For example, during the extraction of pure iron from its ores[2], different technologies are used for the separation process. Depending on the technologies used various

[1] For further knowledge please read the references used
[2] An ore is a type of rock that contains minerals with important elements including metals.

types and amounts of wastes are produced which could directly or indirectly harm the environment. In the manufacturing process, the extracted raw material is used to sculpt new products or components of products. Different energy intensive technologies are used which ultimately contributes to greenhouse gas emissions and waste production. Different impacts in the value chain (phases) are enlisted in tables in each technologies of interest in the following sections. Since EIA only studies the impacts from construction, operation and decommissioning phases, we will be going in details on the particular impacts from only these three phases. These impacts will be discussed according to the technologies in the following.

5.2.1 Environmental impacts of solar thermal

Small scale solar thermal technology is mainly used to heat water for domestic use and are mostly installed on the roof top of a residential building.

According to the study "Environmental impacts from energy sector", during the operation phase two particular environmental impacts are prevalent:

Visual impact: Solar thermal on roof tops of residential households might cause visual impacts on building's aesthetics (Tsoutsos, Frantzeskaki, & Gekas, 2005)**.** The reflection from the glazing mirror could also be a possible impact for the neighbours.
Waste production: Depending on the solar thermal systems, different types of coolant liquids are used. It could be water based or could contain anti-freeze or rust

inhibitors in indirect systems. Such liquids could contain glycol, nitrates, nitrites, chromates, sulphites and sulphates. More complex substances like aromatic alcohols, oils, chlorofluorocarbons (CFCs) etc. are also used in higher temperature applications. Such effluents could pollute water and must be disposed appropriately and handled carefully during operation, to prevent any leakage and consequently cause water pollution**.** (Tsoutsos, Frantzeskaki, & Gekas, 2005)**.** Below gives an overview on further possible environmental impacts from the use of small scale solar thermal systems.

Table 5.1. Environmental impacts from small scale solar thermal technology used for heating.

Raw material acquisition	**Manufacturing**	**Construction**	**Operation**	**Decommission**
Biodiversity loss Habitat loss Toxic-effluents Waste production Depletion of natural resources	Water stress Waste Production	Waste production Air pollution	Visual Impact Waste production	Waste production Air pollution
CO_2 and other GHG gas emissions Noise Pollution (except in operation phase)				

5.2.2 Environmental impacts of concentrated solar power

The environmental impacts of a CSP plant are enlisted in (Wu, et al., (2014).

Table 5.2. Environmental impacts from concentrated solarpower.

Raw material acquisition	**Manufacturing**	**Construction**	**Operation**	**Decommission**
Biodiversity loss Habitat loss Toxic-effluents Waste production Depletion of natural resources	Water stress and pollution Waste production	Biodiversity loss Erosion Water and soil pollution Air pollution	Over consumption of water Visual Impact Soil Temperature decrease Waste production	Dust production Waste production
CO_2 and other GHG gas emissions				
Noise Pollution				

- **Water consumption:** CSP consumes highest amount of water per unit electricity in compare to photovoltaic and wind plants. In a CSP plant which uses the wet technology for cooling of steam from electricity generator, more water is consumed in compare to dry air cooling technology. The water is not only used for the cooling purpose but also to clean the mirrors, because most of the CSP plants are built on semi-arid areas where high solar radiation is present and is prone to dust suspension. In order to reduce the loss of water an efficient water collection and reuse system should be implemented.

- **Decrease in soil temperature:** Due to the shades and altered airflow from the mirror panels in CSP plants, soil temperature change ranging from 0.5 – 4°C were measured in a study from Wu, Z. et al. Such temperature changes could affect those CSP plant areas which are combined with growing crops. Soil temperature change could especially effect those plants which are sensitive to soil temperature. (Wu, et al., 2014).
- **Waste production:** In a CSP plant during its operation different hazardous and non-hazardous wastes are produced. In a study from ACWA POWER on specific environmental and social impact from CSP Plant, possible hazardous waste produced during operation of the plants are sludge from waste water and waste oil treatment processes, waste oil, oily sludge, oily rags, chemical, solvents from general maintenance of site plant machinery, used chemical and fuel drums, soil contamination by potential spills and leaks etc. Such wastes should be disposed appropriately, otherwise can cause harm to human health and the environment. (ACWA Power, 2015).

5.2.2.1. Photovoltaic

During the life cycle of photovoltaic systems several environmental impacts can be observed.

It enlists the impacts in different phases.

Table 5.3. Environmental effects from PV in its life cycle (Hernandez, et al., 2014); own representation

Raw material acquisition	**Manufacturing**	**Construction**	**Operation**	**Decom mission**
Biodiversity loss Habitat loss Waste production Depletion of natural resources	Water stress and pollution Waste production	Biodiversity loss Erosion Water and soil pollution Land use and land coverage change Earth movement by transport movements	Change in microclimate and local hydrology Visual impacts Change in land surface temperature and atmospheric boundary conditions	Dust production Waste production
CO_2 and other GHG gas emissions from other utilities such as vehicles for transport occur				
Noise Pollution				

- **Biodiversity loss, soil erosion and change in land use, and coverage:** Utility-scale PV systems usually require larger area and therefore remove vegetation and grade the soil for their installation. Such activity consequently lead to habitat loss, soil erosion, fragmentation and loss in biodiversity.

- **Ecological impact from transmission lines and corridors:** For a centralized utility-scale PV systems transmission lines and corridors are built to connect with the grid. Such constructions use extensive energy and material. Fragmentation in the forests are also one of the impacts.

- **Waste production:** In every phase of the photovoltaic life cycle some wastes are produced. For example, in the phase of decommissioning, it is important that the PV systems are carefully recycled. PV panels contain toxic materials such as cadmium, arsenic and silica dust. Silica dust if inhaled over long period can cause chronic obstructive pulmonary disease (COPD) (Hnizdo & Vallathan, 2003).

- **Green House Gas emissions:** In the life cycle of a PV system GHG emissions are prevalent. Either during the raw material acquisition or during Operation & Maintenance phase. The emissions are contributed from energy used by different medium such as vehicles for transport.

- **Water consumption:** In order to maintain the efficiency of PV systems, during the operation and maintenance phase water is used to clean the dust deposited in the panels and suppress the dust suspension where it is problematic. In semi-arid areas where water is scarce, high amount of water consumption could be put stress in the surrounding environment and inhabitants.

Table 4 enlists the amount of water consumed per unit electricity in two phases. We can see that PV in compare to CSP and Wind consumes less water per TJh electricity produced.

Table 5.4. Water footprint (WF) per unit electricity from different energy sources. Values in bracket represent the median (Mekonnen, Gerbens-Leenes, & Hoekstra, 2015)

Energy Source	**Construction**	**Operation**	**Total**
	WF (m^3 TJh^{-1})	WF (m^3 TJh^{-1})	WF (m^3 TJh^{-1})
Concentrated Solar Power	84 – 179 (169)	34 – 2000 (559)	118 - 2180
Photovoltaics	5.3 – 221 (86)	1.1 – 82 (19)	6.4 - 303
Wind	0.10 – 9.5(1)	0.1 – 2.1 (0.2)	0.2 - 12

Summary

From all three solar technologies, different types of impacts have been discussed from the phase of construction up-to decommissioning or also only particular phase. This gives an overview on the factors impacting the environment and mitigation measures to be considered during implementation of renewable energy projects, to avoid the impacts or to have them as low as possible. There are many similarities and also differences in the art of impacts on environment (see Figure 5.8). At the end, it is the responsibility of the project developer to seek for a low impact design of the solar technologies as much as possible.

In Figure 5. comparison of the environmental impacts between the three electricity generating technologies CSP, Photovoltaic and Wind during their life cycle under three impact categories starting from raw material acquisition until the decommissioning are represented. This figure provides an overview on which type of technologies and within the particular technology which type of materials and system used have different extent of impacts on environment. For instance, PV made from copper indium gallium selenide (CIGS) mounted on roof and CIGS PV mounted on ground has different extent of impact in all three-impact category. Comparing the technologies regarding only these three categories, we could see that wind energy technology has the least impacts. In chapter 6 the wind energy technology and its environmental impacts will be further discussed.

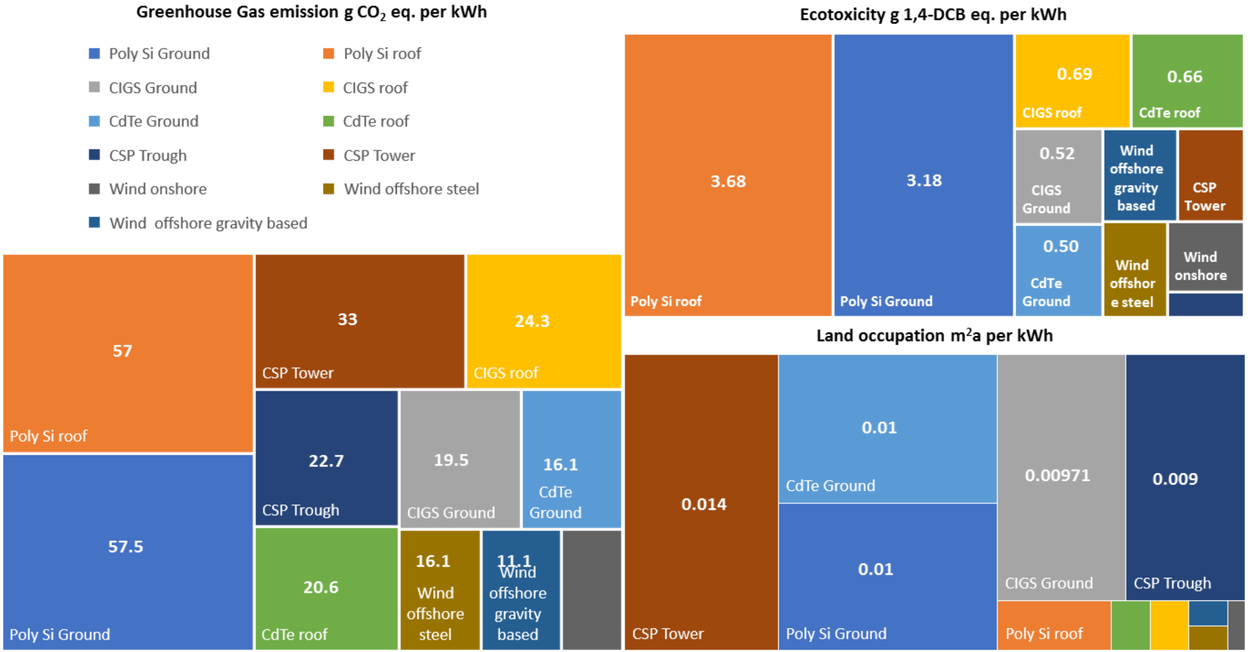

Figure 5.8. Environmental Impacts from Photovoltaic, Concentrated Solar Power and Wind Power per kWh electricity produced (Polycrystalline Silicon (Poly Si), Copper Indium Gallium Selenide (CIGS), Cadmium Telluride (CdTe) (Hertwich, et al., 2014) eq. = equivalent, CFC = Chlorofluorocarbon, DCB = Dichlorobenzene, m^2a = square meter year; own representation

References

ACWA Power. (2015). *Specific Environment and Social Impact Assessment.* Ouarzazate Morocco. Retrieved July 14, 2017, from http://documents.worldbank.org/curated/en/618461468274482428/pdf/E44890V90P131200Box391417B00PUBLIC0.pdf

Corona, B., Cerrajero, E., López, D., & San Miguel, G. (2016, June 29). Full environmental life cycle cost analysis of concentrating solar power technology: Contribution of externalities to overall energy costs. *Elsevier, 135*, pp. 758 - 768. doi:10.1016/j.solener.2016.06.059

Fthenakis, V., & Kim, H. (2011, February 23). Photovoltaics: Life-cycle analyses. *Solar Energy, 85*, pp. 1609 - 1628. doi:10.1016/j.solener.2009.10.002

Hernandez, R. R., Easter, S. B., Murphy-Mariscal, M. L., Maestre, F. T., Tavassoli, M., Allen, E. B., . . . Allen, M. F. (2014, August 11). Environmental Impacts of utility-scale solar energy. *Reenwable and Sustainable Energy Reviews, 29*, pp. 766 - 779. doi:10.1016/j.rser.2013.08.041

Hnizdo, E., & Vallathan, V. (2003, April 1). Chronic obstructive pulmonary disease due to occupational exposure to silica dust: a review of epidemiological and pathological evidence. *Occupational and Environmental Medicine, 60,* pp. 237 - 243. doi:10.1136/oem.60.4.237

Mekonnen, M., Gerbens-Leenes, P., & Hoekstra, A. (2015, March 9). The consumptive water footprint (WF) of electricity and heat: a global assessment. *Environmental Science: Water Research and Technology, 1,* pp. 285 - 297. doi:10.1039/c5ew00026b

Tsoutsos, T., Frantzeskaki, N., & Gekas, V. (2005). Environmental impacts from the solar energy technologies. *Energy Policy*(33), pp. 289 - 296. doi:10.1016/S0301-4215(03)00241-6

Wu, Z., Hou, A., Chang, C., Huang, X., Shi, D., & Wang, Z. (2014). Environmental impacts of large-scale CSP plants in northwestern China. *Environmental Science Processes & Impacts, 16*, pp. 2432 - 2441. doi:10.1039/C4EM00235K

CHAPTER 6

WIND ENERGY

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Abstract: The use of solar energy can be classified as direct (e.g. solar thermal or photovoltaics) or indirect (e.g. wind, hydro or bioenergy). This chapter is dealing with one of the indirect use of solar energy: In the first part physical and technological basics from the use of wind energy are outlined.

Despite the water footprint of a wind plant is comparably less than a PV and CSP plant, there are various environmental impacts during the construction, operation and decommissioning phases of wind energy projects, which are summarized in the second part of the chapter.

Learning objectives:

At the end of this chapter, the student will be able to:

- Readers will be informed about the wind energy technology
- Readers are able to evaluate the environmental impacts of wind energy use along its life cycle

6.1 Wind energy

Wind is used in wind turbine to produce energy. Wind turbines as it already explains itself uses wind as source of energy. Wind energy originates from the sun. Solar radiation falls onto the earth and the temperature difference between the equator and the poles drives thermal currents – or winds – which circulate around the globe. The atmosphere is a big thermal machine continuously “producing” wind.

Air mass flows between areas of low and high pressure. Up to now, winds in up to about 200 m above ground level can be “harvested” by the wind industry. Wind turbines can generate electricity at wind speeds of 3 m/s to 35 m/s. Some specially designed wind turbines can work even at lower or higher wind speeds. Hurricanes, typhoon, tornados or thunderstorms are not useful because they are very strong and can cause serious damages to the wind turbine.

Wind often changes its velocity and its direction. Rapid fluctuations are called gusts and lulls. A gust is a sudden increase in wind speed and lulls are sudden drops in wind speed. These gusts and lulls are caused by turbulences.

6.2 Wind turbine elements

General design

Wind turbines can be constructed to withstand strong storms, operate under arctic or tropical weather conditions, in the sea in front of coasts or in deserts.

Quite a wide range of different designs exist for special purposes.

Wind turbines are designed with a vertical or horizontal axis, one blade up to about 20 rotor blades, small capacity of some watt up to some megawatt, with or without gear box and with direct current or alternating current generator. A general design does not exist, although the three-bladed horizontal upwind turbines are the most successful ones. With these turbines, the rotor blades are facing the wind while with downwind turbines the nacelle is facing the wind.

The primary components of a wind energy system are:

- Rotor blades
- Nacelle and controls
- Generator and electronics
- Tower components

Figure 6.1 represents the components of a wind turbine and Table 6.1 gives an overview of materials used in the component. In the following section, the detailed information on the components is explained.

6.2.1 Rotor Blades

Rotor blades "capture" the wind and convert its motive energy into the rotation of the hub (see Figure 6.1). The hub directs the energy from the rotor blades on to the generator. If the wind turbines have a gearbox, the hub is connected to the slowly rotating gearbox shaft, converting the energy from the wind into rotation energy. If the turbine has a direct drive, the hub passes the energy directly on to the ring generator. Each manufacturer has its own rotor blade concepts and conducts research on innovative designs; there are many variations that are quite different. In general, though, all modern rotor blades are constructed in a similar way to airplane wings (World Wind Energy Association, 2011).

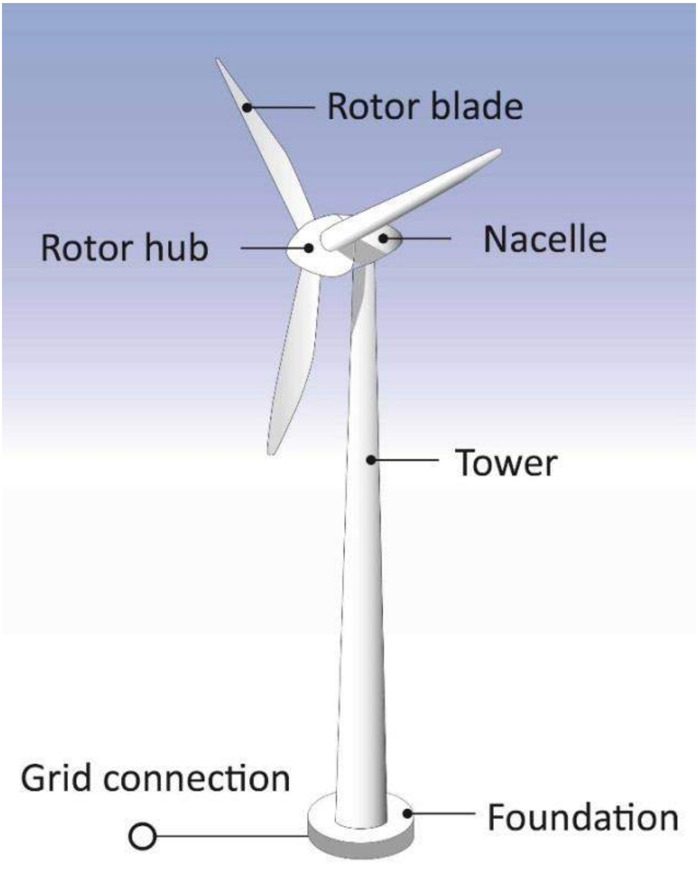

Figure 6.1. Scheme of a wind energy turbine with components (RENAC, 2017)

Table 6.1. Material used in wind turbine components

Component	**Material**
Foundation	Concrete, steel
Tower	Steel, concrete
Drive train	Cast iron, steel lubricants
Generator	Cast iron, copper, electronics
Electronics	Cable, switchboard
Nacelle	Metals, fibre components
Rotor blades	Fibre components, sandwich core

Wind turbine rotor blades utilize the same "lift" principle as airplanes or birds: because of the shape of the wing, the stream of air below the wing is slower than on the upper side. For this reason, it is the other way around with the pressure. Above the wing the pressure is lower than under the wing. This leads to a pressure difference (lift effect). These forces make the rotor rotate.

It has been found out that the three-blade rotor is the most efficient one for power generation by large wind turbines. The three rotor blades allow for a better distribution of mass, which makes rotation smoother and also provides for a "calmer" appearance. The rotor blades mainly consist of synthetics reinforced with fiberglass, carbon fibres, wood and metal (lightning protection, etc.).

The layers are usually glued together with epoxy resin. Aluminium and steel alloys are heavier and suffer from material fatigue. Therefore, these materials are generally only used for very small wind turbines. (World Wind Energy Association, 2011)

6.2.2 Nacelle

The nacelle holds all the turbine machinery. Because it has to be able to rotate to follow the wind direction, it is connected to the tower via bearings. The nacelle includes the drive train that consists of the following components: rotor shaft with bedding, gear box (direct drive turbines have none), brake(s), coupling, generator, power electronics, cooling/heating and a small crane.

The details of the arrangements in the nacelle vary from manufacturer to manufacturer.

6.2.3 Wind turbine towers

Wind turbine towers are made of concrete, metal, wood or a combination of these materials. Most large wind turbines are built with tubular steel towers, which are manufactured in sections. Steel towers, concrete towers, lattice tower, Hybrid towers and guyed tubular towers are the types of wind towers available.

Steel towers usually consist of two to four segments. Each has a length of 20 – 30 meters with flanges at either end. They are bolted together on the wind farm site.

Concrete towers can be made by using specially developed sections fastened together at wind farm site. The tower sections themselves are manufactured entirely in a pre-casting plant. It is also possible that the tower is completely constructed on site with a climbing formwork (called in-situ concrete).

The lattice tower construction method is based on the principle of using material only at points where forces have to be fed into the structure. By using this method, it is possible to reduce the weight of the tower.

Hybrid towers combine a pre-cast concrete segmented tower with tubular steel sections on top. The advantage is that the segments can be easily transported via ordinary trucks especially in those countries where the transportation of steel towers with large diameters is problematic and where the concrete segments can be produced locally.

Guyed tubular towers are only used for small wind turbines. They are light and can be set up without a crane.

6.3 Environmental impacts from wind energy use

In a wind power plant various environmental impacts during the construction, operation and decommissioning phases occur. Table 6.2 enlists the potential environmental impacts from a wind energy plant. For instance, water footprint of a wind plant is comparably less than a PV and CSP Plant. Impacts during operation of the wind farm will be discussed in the following points.

Table 6.2. Environmental Impacts from Wind Energy Plant (Hernandez, et al., 2014 and Saidur, Rahim, Islam, & Solangi, 2011).

Raw material acquisition	**Manufacturing**	**Construction**	**Operation**	**Decommission**
Biodiversity loss Habitat loss Toxic-effluents Waste production Depletion of natural resources	Water stress and pollution Waste Production	Biodiversity loss Water and soil pollution Earth movements from transport movements	Impacts on wildlife Visual Impact	Dust production Waste production
CO_2 and other GHG gas emissions				
Noise Pollution				

6.3.1 Impacts on wildlife

There are many studies showing the impacts on avian species due to wind plants (H Kunz, et al., 2007) (Drewitt & Langston, 2006) (Saidur, Rahim, Islam, & Solangi, 2011). In compare to the number of birds killed from hunting, the number of deaths due to wind farm is minimal. But still such cases from wind plant can be avoided with a proper study of the site beforehand to have the smallest impact as possible. A study from S. Mariò et al. titled “Predicting the trends of vertebrate species richness as a response to wind farms installation in mountain ecosystems of northwest Portugal” explained that during poor weather or foggy night, the lights emitted from wind plants attracts the birds and increase their vulnerability from collision with wind turbine blades (Santos, et al., 2010). Design of the tower in wind plant is also one of the factor for bird mortality. Older turbines with lower hub heights, shorter rotor diameters cause the blades to spin at high RPM and consequently higher vulnerability for bird mortality rate (Magoha, 2002).

6.3.2 Visual Impacts

Depending upon wind energy technologies, their color, size, distance from the residences and shadow flickering, the impacts from a wind plant may vary (Ladenburg, Visual impact assessment of offshore wind farms and prior experience, 2009). To reduce the visual impact the wind turbines are colored green at the base and gradually painted in light grey color in the top. Shadow flickering occurs either by moving blade or the reflection of sun ray on the wind turbine body, so called disco effect occurs (Saidur, Rahim, Islam, & Solangi, 2011).

This effect does not last for long and only in certain specific combined circumstances, e.g. when,

- the sun is shining at a low angle, and
- the turbine is directly between the sun and the affected property, and
- the wind speed is above cut in wind speed of the turbine (to ensure that the turbine blades are moving). (Department of the Environment, Heritage and Local Government of Ireland, 2006)

Shadow flicker can be influenced by careful site selection, design and planning.

6.3.3 Noise impacts

In a wind turbine noise emitted could be categorized as aerodynamic or mechanical type. Noise created from movements of gear box, electrical generator and bearings are the mechanical type and noise developed by the flow of air over and past the blades of a turbine is aerodynamic type. Such noise varies with the size of the turbine, wind directions and may disturb the residents nearby. The noise impacts are also seen as one of the reasons for decrease in land value near a wind plant. Mechanical noises during operation could be reduced using insulation curtains and anti-vibration support footings. Aerodynamic noise could be minimized by designing the blades in such a way, that minimum noise is created during the movement (Saidur, Rahim, Islam, & Solangi, 2011) (Gauld, 2007). To ensure public acceptance at noise sensitive locations such as hostel, hospital, residential areas etc., a careful planning of wind farm layout becomes essential. For instance, in a state from Germany known as Bavaria, to avoid any impacts from wind farms, a rule has been implemented stating the distance between a wind turbine and residential areas to be 10 times the height of the wind turbine.

References

Department of the Environment, Heritage and Local Government of Ireland. (2006).

Drewitt, A., & Langston, R. (2006). Assessing the impacts of wind farms on birds. *International journal of avian science, 148*, pp. 29 - 42.

Gauld, R. (2007). *Wind developments: Ecological, technical and social impact considertions.* Orkney Sustainable Energy Ltd.

H Kunz, T., Arnett, E. B., Erickson, W. P., Hoar, A. R., Johnson, G. D., Larkin, R. P.,Tuttle, M. D. (2007). Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. *Frontiers in Ecology and the Environment, 5*(6), pp. 315 - 324.

Ladenburg, J. (2009). Visual impact assessment of offshore wind farms and prior experience. *Applied Energy, 86*, pp. 380-387.

Ladenburg, J. (2009). Visual impact assessment of offshore wind farms and prior experience. *Applied Energy, 86*, pp. 380-387. doi:10.1016/j.apenergy. 2008.05.005

Magoha, P. W. (2002). Footprints in the wind?: enviornmental impacts of wind power development. *Fuel and Energy Abstracts, 3*(5), pp. 30-33. doi:10.1016 /S1471-0846(02)80083-X.

Mário S, B. R. (2010). Predicting the trends of vertebrate species richness as a response to wind farms installation in mountain ecosystems of northwest Portugal. *Ecological Indicators, 10*, pp. 192 - 205.

Renewables Academy (RENAC) AG. (2017). Environmental and social standards in renewable energy (PV, wind and biomass) project finance. Berlin, Germany.

Saidur, R., Rahim, N., Islam, M., & Solangi, K. (2011). Environmental impact of wind energy. *Reenwable and Sustainable Energy Reviews*, *15*(5), pp. 2423 - 2430. doi:10.1016/j.rser.2011.02.024

World Wind Energy Association. (2011).

CHAPTER 7

WAVE, TIDAL AND HYDROGEN ENERGY

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Abstract: This chapter deals with potentials of wave and tidal energy source for electricity production. The possibilities and limitations of using this technology are discussed. Technological development, covering tidal turbines, tidal barrages and wave capturing devices is presented. Environmental impact of wave and tidal energy is evaluated.

Industrial production of Hydrogen gas and its impact on environment are elaborated. Once Hydrogen is produced it is almost an excellent energy carrier. It can be used in fuel cells for generate electricity and heat. Technological aspects of storing, transporting and using Hydrogen gas are presented. Reliability and economical aspects of Hydrogen gas application are discussed.

Learning objectives:

After mastering this chapter, the student will have the ability to:

- Understand the potentials of the wave and tidal as renewable energy source

- Understand and discuss potential environmental impacts of wave and tidal as energy sources
    - Critically discuss the questions related the advantages and disadvantages of wave and tidal
- Understand and discuss potentials of hydrogen as energy source
- Critically discuss the different hydrogen production technologies, advantages and disadvantages
- Critically discuss environmental impacts of hydrogen production and use

7.1 Wave and tidal potential for electricity production

The term ‘wet renewables’ is commonly used to refer to offshore wind energy developments as well as tidal barrages/fences, tidal stream and wave energy schemes (Frid et al., 2012). Using these energy resources is especially prominent for the countries with significant areas of coastal waters. The World Energy Council estimates that if less than 0.1% of the renewable energy within the oceans could be converted into electricity it would satisfy the present world demand for energy more than five times over (Council, 2016). Although there is estimation that nearly 3000 GW of tidal energy is available worldwide, less than 3% is located in areas suitable for power generation, according to the World Offshore Renewable Energy Report 2002-2007 (Esteban & Leary, 2012). Unfortunately, only a small fraction of this ocean energy resource can be found in sites that are economically feasible using the available technology. It has been documented that 48% of the European tidal resource is located in the UK, 42% in France, and 8% can be found in Ireland. Wave Energy has an estimated potential of approximately 1,000-10,000 GW, which is in the same order of magnitude as world electrical energy consumption. The important advantage of tidal currents as an energy source over waves (or wind) is its predictability, since the tides can be accurately predicted weeks or even years in advance.

Tides

What makes the research on tidal energy so attractive is the regularity of the tides as well as the enormous energy potential (Pelc & Fujita, 2002). A tide is the regular rise and fall of the surface of the ocean caused by the gravitational force of the sun and moon on the earth and the centrifugal force produced by the rotation of the earth and moon about each other. Taking into account that moon is closer to earth, its gravitational force is 2.2 times larger than the gravitational force of the sun. Tidal currents can be found in coastal areas and in places where the waterflow is forced to navigate through narrow channels. These currents flow in two directions; the flow oriented in the direction of the coast is called the flood current, while the one withdrawing from the coast is known as the ebb current. Tidal energy consists of the potential and kinetic component. Therefore, the tidal power generating facilities can be categorized into two main types: tidal barrages which use potential component, and tidal current turbines, which use kinetic energy.

Tidal barrages

Tidal barrage is a type of tidal power generation that involves the construction of a low dam wall ("barrage") across the entrance of a tidal inlet or basin creating a tidal reservoir (http://www.alternative-energy-tutorials.com.html) (see Figure 7.1). This dam has underwater tunnels placed along its width which navigate the sea waterflow through them using "sluice gates". Inside the tunnels there are fixed water turbine generators that use the water kinetic energy to generate the tidal electricity. A tidal barrage has the same operating principle as hydro-electric power generation, with the difference that tides flow in two directions so the generators are designed to handle both directional water flows.

The tidal range is the vertical difference between the high and low tide sea level (""http://www.alternative-energy-tutorials.com.html "). Considering that the tide is moving in a vertical direction between low and high level, on its way down it creates height differential where the potential energy is stored. This head is used to create a difference in water levels on two side of the dam, and the electricity is produced while water passes through the turbines. There are three main tidal energy barrage schemes in use:

- **Flood generation:** the tidal power is generated as the water enters the tidal reservoir on the incoming tide.
- **Ebb generation:** the tidal power is generated as the water leaves the tidal reservoir on the ebb tide.
- **Two-way generation:** the tidal power is generated as the water flows in both directions during a flood and ebb tide.

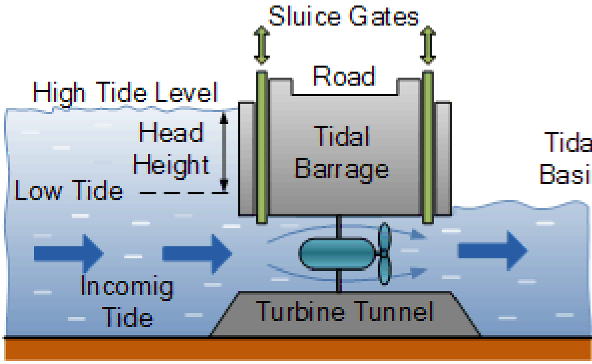

Figure 7.1. Tidal barrage (("http://www.alternative-energy-tutorials.com.html)

For the Ebb generation tidal barrage during the flood tide, the sluice gates are opened to allow the tide to flood into the tidal basin (estuary, fjord or bay). At high tide the sluices in the barrage are closed, capturing the water in the basin. Once a sufficient height differential has occurred the turbines gates opens and the contained water flows out across the turbines. The electricity generation continues until the hydrostatic head drops to the minimum level that allows efficient operation of turbines. The sluices are then opened to allow the basin to refill. This operation method (ebb generation), generates the most power. It is also possible to generate power on the flood tide by refilling the basin through the turbines. Both tidal flows may be harnessed in dual mode devices. The first tidal barrages were built in 1966, when the plant at La Rance (France) was put into operation (see Figure 7.2), and is still operating today (Esteban & Leary, 2012). The only country that is currently working on serious implementation of these systems is South Korea. Other countries are still evaluating the economic aspects of these plants, considering the significantly high infrastructure investments that are required, as well as the potential environmental damage. The first commercial farms have just recently been put into operation, with the Pelamis project (in Portugal) and SeaGen (in Northern Ireland) which have been set up in the summer of 2008.

The tidal barrage construction requires huge amount of materials in order to substain the enormous load coming from dammed water (Rourke, Boyle, & Reynolds, 2010). The greatest disadvantage of tidal barrages is their negative environmental impact. Building a dam across an estuary or bay may influence the natural tidal flow, affecting the marine life within the estuary, as well as the water quality and sediment transportation. The tidal barrage influences fish and other marine animals, but also maritime traffic. In case of ebb generating system, this problem is not so significant, due to the fact that the basin is kept at higher water level comparing to flood generating system.

Tidal turbines

Tidal current turbines use the kinetic energy of the tidal flow to generate electricity (Rourke et al., 2010). The similarity with wind energy technology is evident at first sight, since tidal stream generators resemble to underwater wind farms. However due to the differences in density and speed between the air and water, there are several operational differences in the operating conditions. The off-shore wind power generators can be damaged by storms or sea, while tidal turbines are located below the sea level, or fixed to the sea bed. Considering that turbines are submerged in water, they are exposed to greater force and moments comparing to wind turbines. They are designed to endure significant loads in the period when they are not generating electricity, as well as to be able to produce electricity during both direction of tide movements (flood and ebb).

There are two most common methods of tidal current energy extraction:

- Horizontal axis tidal current turbines. The turbine blades rotate about a horizontal axis which is parallel to the direction of the flow of water.
- Vertical axis tidal current turbines. The turbine blades rotate about a vertical axis which is perpendicular to the direction of the flow of water.

The major tidal currents can be found in the following locations: Arctic Ocean, English Channel, Irish Sea, Gulf of Mexico, Amazon, Straits of Magellan, Gibraltar, etc. (("http://www.alternative-energy-tutorials.com.html "http://www.alternative-energy-tutorials.com.html ").

Wave energy utilization

The main disadvantage of wave power as an energy source (since it is caused by the wind), is its mostly random variability, although some seasonal patterns can be found (Antonio, 2010). The oil crisis in 1970s led to the significant increase of interest in energy production from waves. The wave energy absorption is a complex hydrodynamic process that involves considerable theoretic difficulties. Therefore, the first papers related to wave energy were mostly theoretic. Since the European Commission in 1991 included wave energy in R&D programme, the first projects have started to develop. Currently, there is a wide variety of wave energy capture technologies, resulting from the different ways in which energy can be absorbed from the waves. The selected technologies also depend form the water depth and the location (shoreline, near-shore, offshore). The first prototypes were shoreline devices which have the advantage of easier installation and maintenance, and do not require deep-water moorings and long underwater electrical cables. The typical first-generation device is the oscillating water column with air turbine. The oscillating water column consists of partially submerged structure opened bellow the water surface (see Figure 7.2). The oscillating water motion produced by waves is forcing the air to flow through the turbine that drives the electric generator.

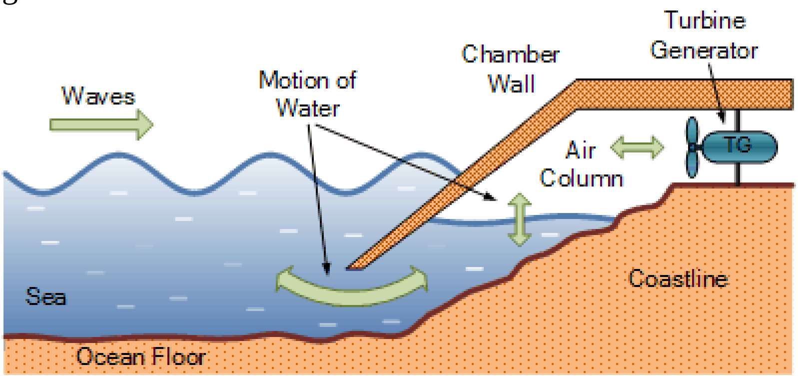

Figure7.2. Oscillating water column ("http://www.alternative-energy-tutorials.com.html ,)

The type of wind turbine generator used in an oscillating water column is the key element to its efficiency. The air within the chamber is constantly changing movement direction caused by the vertical (up and down) movement of water, causing the sucking and blowing effect through the turbine. To overcome this problem the type of wind turbine used in these systems is called a **Wells Turbine**. The Wells turbine has the remarkable property of rotating in the same direction regardless of the direction of air flow in the column. The kinetic energy is extracted from the reversing air flow and used to drive an electrical induction generator. This technology produces no GHG emissions making it a non-polluting and renewable source of energy, created by natural transfer of wind energy through a wells turbine. The advantage of this shoreline scheme is that the main moving part, the turbine can be easily removed for repair or maintenance because it is on land. The disadvantage is that, the oscillating wave columns output is dependent on the level of wave energy, which varies day by day according to the season.

Off-shore devices are oscillating bodies floating on water that are able to exploit the more powerful waves that can be found in deep water (see Figure 7.3). The simplest wave capture devices consist of heaving buoy reacting against the fixed frame (sea bottom or structure that is fixed to bottom). The pitching and heaving of the waves causes a relative motion between an absorber and reaction point. The linear absorber (wave attenuator) floats on the surface of the water. It is tethered to the ocean floor so that it can swing perpendicularly towards the incoming waves. As the waves pass along the length of this snake like wave energy device, they cause the long cylindrical body to sag downwards into the troughs of the waves and arch upwards when the waves crest is passing. Connecting joints along the body of the device flex in the waves exerting a great deal of force which is used to power a hydraulic ram at each joint. The hydraulic ram drives oil through a hydraulic motor which drives a generator, producing the electricity.

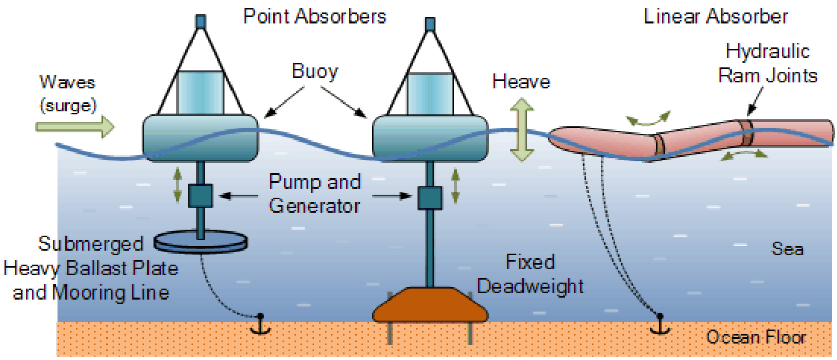

Figure 7.3. Wave capture devices ("http://www.alternative-energy-tutorials.com.html)

Other ocean energy potentials

Ocean thermal energy conversion (OTEC) shown in Figure 7.4, produces electricity from the natural thermal gradient of the ocean, using the heat stored in warm surface water for evaporation, while cold, deep water from a depth of 1,000 m for cooling (condensation) (Pelc

& Fujita, 2002). In this process working fluid such as ammonia is alternatively evaporated and condensed to power a Rankin cycle. Usually, the energy in the evaporated ammonia is captured with a turbine, which turns a generator to produce electric power for a utility grid. OTEC is possible in locations with large temperature differences, extracting energy with a heat engine. In total, it is estimated that about 10TW of power, approximately equal to the current global energy demand, could be provided by OTEC without affecting the thermal structure of the ocean.

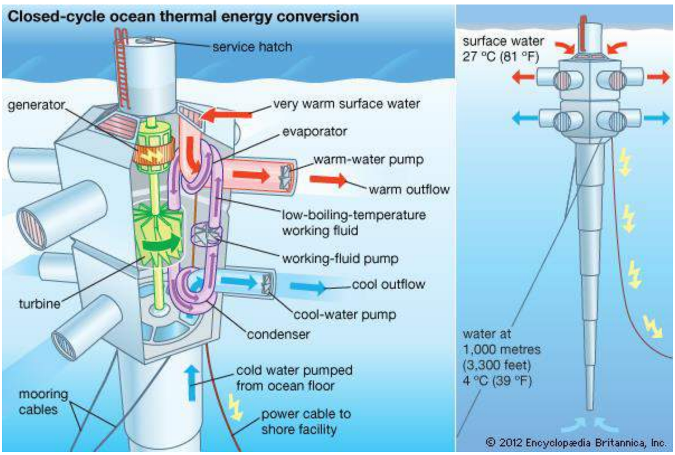

Figure 7.4. Ocean thermal energy conversion ("https://www.britannica.com/technology/ocean-thermal-energy-conversion,")

Salinity gradients also can be exploited for energy extraction through the osmotic process. The cultivation of marine biomass can yield many useful products, including renewable fuels for electricity generation. However, due to technology limitations and economic considerations, osmotic and thermal energy developments are limited.

7.2 Environmental impact of wave and tidal energy

So far, tidal fences and wave energy capture devices have only been operated as several experimental models, so the prediction of their environmental impacts is based on very limited empirical data. It has been shown that the tidal barrages by building a dam across a bay, potentially have significant environmental impact, that is evident in places such as bird feeding areas, nursery or spawning areas. These impacts can be divided into three main categories: 1) impacts on habitats and species, 2) direct impacts on reproduction and recruitment, and 3) impacts on water column processes and hydrology. Tidal barrage affects the reproduction and migration of species and influences habitats both upstream and downstream of the facility. Wave energy collector, depending on their configuration, can also alter maritime habitat caused by the moving parts of the energy system (Frid et al., 2012).

Considering that the lifecycle of the barrage is greater than 100 years, these impacts are long term and they should be carefully investigated. The changes in the tidal regimes and water retention have impact on bird communities and benthic habitat availability. If the site was on a fish migration route (salmonids, eels, shad) it is necessary to provide adequate passage for fish, although a certain degree of loss of the regional habitat pool is inevitable (Pelc & Fujita, 2002). Changes caused by the barrage include also reduction in intertidal area, slower currents, reduced range of salinities and changed bottom water characteristics. More recent innovations include tidal fences that consist of turbines stretching entirely across a channel where tidal flow sets up relatively fast currents (see Figure 7.5).

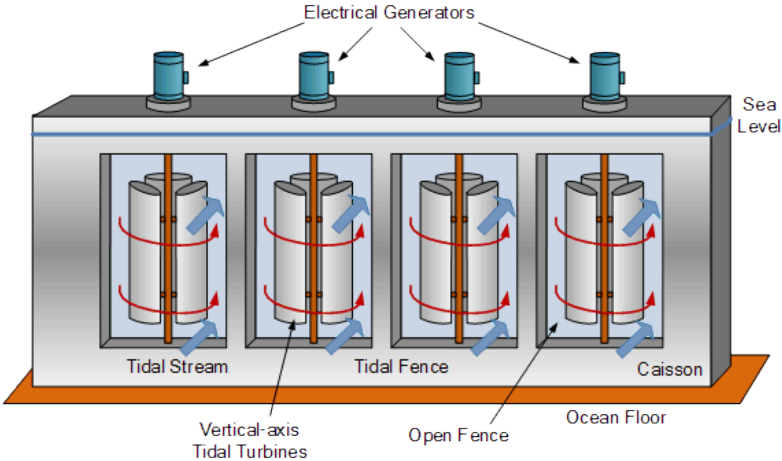

Figure 7.5. Tidal fence (""http://www.alternative-energy-tutorials.com.html ")

The turbines are designed to allow the passage of fish, water and sediment through the channel. Tidal plants located at the mouths of estuaries cause the same environmental problems as large dams. By altering the flow of saltwater through the estuaries, tidal plants could impact the hydrology and salinity of these sensitive environments. Estuaries serve as a nursery for many marine organisms as well as a unique and irreplaceable habitat for estuarine organisms, and alteration of this habitat by the construction of large tidal plants should be avoided. During the construction phase for the tidal plant at La Rance, the estuary was entirely closed off from the ocean for 2–3 years, and there was a long period before the estuary reached a new ecological equilibrium. In the future, the construction of any new tidal barrage should not totally close off the estuary from the ocean. These plants should not be built until detailed environmental assessments demonstrate a minimal impact on the marine ecosystem. Tidal fences and tidal turbines are likely to be more environmentally benign. Tidal fences may have some negative environmental impacts, as they block off channels making it difficult for fish and wildlife to migrate through those channels. Marine mammals could be protected by a fence that would keep larger animals away and a sonar sensor system that shuts the system down when marine mammals are detected. Tidal turbines could be the most environmentally friendly tidal power option. They do not block channels or estuarine mouths, interrupt fish migration or alter hydrology. Tidal turbines and tidal fences both may offer considerable generating capacity without a major impact on the ocean, while tidal barrages are probably too damaging to the marine ecosystem. The tidal energy projects should be sited and built so that major migration channels are left open. Turbines should turn slowly enough that fish mortality is minimized and nutrient and sediment transport is largely unaffected. Wave energy converters had only minor direct effects on the benthic community (macrofaunal biomass, densities, species richness and biodiversity) in relation to natural high variability.

7.3 Hydrogen energy

Hydrogen is the third most abundant element in our surroundings, but it is always bonded with other elements, creating compounds, such as methane (CH_4), water (H_2O), and ammonia (NH_3). The fact that it cannot be found freely (it has to be separated prior to the use) has significant impact on its value as an energy source. This extraction process requires significant amount of energy, while the used energy source can be renewable or fossil fuel. Hydrogen is often referred to as the „fuel of the future", and there are number of advantages that can justify that title (Tabak, 2009). It burns easily, and it releases significant amount of heat per unit mass. Hydrogen can also be used to power energy conversion devices called fuel cells by applying process that is more efficient than combustion. Theoretically, hydrogen is renewable energy source considering that water is both a source of hydrogen and a product of its use. The advantages of hydrogen lead to the fact that many researchers believe that the hydrogen is the one that will eventually replace the fossil fuels. However, currently there are significant barriers to its widespread practical use:

- It is expensive to produce and to transport.
- As an automotive fuel, it is difficult to store on board in amounts large enough to provide drivers with a practical driving range.
- Fuel cells have so far proved to be expensive to manufacture and too prone to failure for use in many practical applications.

What makes hydrogen technologies so interesting is the potential to address two very important issues in current stage of energy system development: energy storage for intermittent energy sources (especially renewables) and fuel for transportation (instead of fossil ones) (Leveque et al., 2010). In general, the fossil fuel based hydrogen production technologies are well developed at this moment, although it is necessary to implement significant improvement in order to achieve widespread industrial production. Sustainable large-scale hydrogen production using fossil fuels will require carbon capture and storage technology (CCS). Using natural gas for hydrogen production can cause some problems in supply security in Europe. These facts, considering also economic aspect, implicate that the hydrogen production from coal is better alternative.

Scientists presented some issues that could affect the development of the renewable hydrogen future. Whereas the energy losses in an efficient electrical grid are about 10%, if hydrogen is used as storage and transport medium, these losses become 75-80%. Therefore, this inefficient electricity–hydrogen–electricity pathway seems incompatible with a sustainable energy future. Second, if hydrogen is used as storage medium for other renewable energy sources it means that the hydrogen should be produced only in cases of excess electricity production. That implicates that the penetration of renewable energy sources needs to be considerable before hydrogen can be effectively produced. However, this kind of very low and highly irregular production of hydrogen has a detrimental effect on the efficiency of electrolysers. Third, non- intermittent renewable energy sources may also not be available for hydrogen production. Biomass already has different application purposes, while large fraction of crop must be kept for soil fertility purposes, which affects the potential available amount. Also electricity from large-scale hydropower plants is not recommended, since the environmental impact of these plants has proven to be significant, which makes them considered as non-renewable. There is a question of price of the required infrastructure development, especially in cases of low production capacities. Rather than completely turning to the bond between hydrogen and renewables, it is recommended to explore other hydrogen production technologies and to carefully investigate the interaction between hydrogen and other energy carriers. Huge costs of current technologies for hydrogen production and transport are raising the question of the possible end use that can justify the investment. At this moment hydrogen use is limited to the applications of fuel cells, where reliable electricity generation with very low local environmental impact is required. These applications have stimulated significant advances in fuel cell technologies. Use of hydrogen in transportation is viewed by many as the real justification of a hydrogen economy. At present, low-temperature fuel cells suitable for vehicle use cost around €8,000/kW. It is estimated that the cost should be decreased by two orders of magnitude in order to be competitive. Dual fuel (hydrogen and gasoline) engines, already developed by car manufacturers, emit much lower levels of organic compounds and other contaminant emissions.

7.3.1 Hydrogen Production Technologies

Technologies for hydrogen production can be roughly divided into three main categories: electrolytic, thermochemical and biological hydrogen production. An overview of the potential sources and extraction technologies is presented in Figure 7.6. Extracting hydrogen from feedstock is generally low-efficient process that can sometimes require even more energy than it can produce.

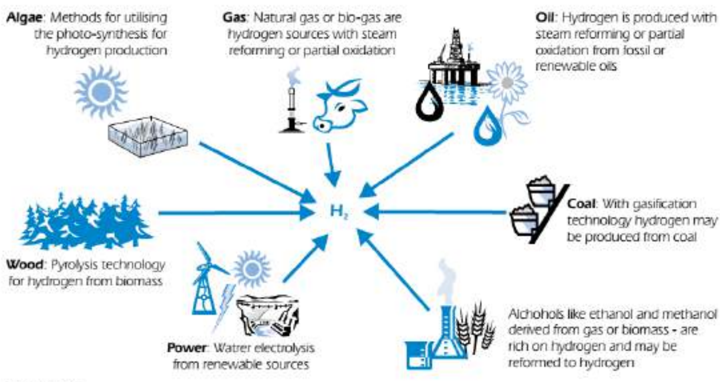

Figure 7.6. Feedstocks and process technologies for hydrogen production (IEA, 2006)

Hydrogen can be produced from water, biomass, natural gas, or coal (after gasification) (Turner, 2004). Today, hydrogen is mainly produced from natural gas via steam methane reforming.

Water electrolysis

Water electrolysis is a well-known, commercially available technology for very clean hydrogen production. It is the process of splitting water into hydrogen and oxygen with application of electrical energy, as in equation

$$H_2O + \text{electricity} \rightarrow H_2 + \frac{1}{2}O_2$$

The advantage of this process is that it enables decentralized operation, which makes infrastructure far more simple comparing to hydrogen production from fossil fuels or biomass. In order to this technology becomes economically viable, it is necessary that electrolytic equipment becomes significantly cheaper and more efficient, or that electricity price becomes smaller comparing to gas or coal prices. Considering that with higher temperatures required electrical energy decreases, for sites where there high-temperature level heat is available, the high-temperature electrolysis systems may be preferable.

Production from coal

Coal gasification could be technology that produces considerable amounts of hydrogen and electricity thanks to the significant available coal deposits. Also, because of its relatively low cost, it is often cited as the best resource for economically producing large quantities of hydrogen. A typical reaction for the process in which carbon is converted to carbon monoxide and hydrogen is given in equation

$$C(s) + H_2O + \text{heat} \rightarrow CO + H_2$$

The CO is further converted to CO_2 and H_2. However, the energy required for the necessary sequestration of CO_2, which is a leading by-product in all fossil fuel hydrogen production technologies, increases the coal consumption. The hydrogen production using solar, wind, nuclear and geothermal energy include electrolysis of water, thermal chemical cycles using heat, and biomass processing. Biomass can easily be converted into a number of liquid fuels, including methanol, ethanol, biodiesel, and pyrolysis oil, which could be transported and used to generate hydrogen on site. Although biomass is clearly sustainable, it cannot supply hydrogen in the amounts required.

Thermochemical water splitting

Because the direct thermal splitting of water requires temperatures higher than 2000°C and the product is rapidly recombining mixture of hydrogen and oxygen, scientists investigated different thermal chemical cycles that can use lower temperatures and produce hydrogen and oxygen in separate steps. One of the most common method requires use of sulfuric acid (H_2SO_4) at 850°C and hydrogen iodide (HI) at 450°C. However, it is necessary to achieve material properties that can meet the required stability under the operating conditions of HI and H_2SO_4. For safety reasons, long heat transfer line is required in order to keep this plant far from the reactor. Solar thermal systems could also be used to drive such thermal chemical cycles. Any technology that produces electricity can drive an electrolyzer to produce hydrogen. Because of the enormous potential of solar and wind, it seems possible these sources can be more widely used in future. The efficiency of the electrolyzers available on the market is in range from 60 to 73%, so one often stated issues is its low efficiency. However, although for sure it is very important, the efficiency itself should not be the determining factor, especially for deciding on new technologies. The energy required to split water can be obtained from a combination of heat and electricity. The amount of water needed to produce hydrogen for transportation is not great. Conversion of the 230 million vehicles to fuel cell vehicles would require about 100 billion gallons of water/year to supply the needed hydrogen. Sustainable hydrogen production technologies that may affect hydrogen production in the future include photobiological and photoelectrochemical approaches (see Figure 7.7). These systems produce hydrogen directly from sunlight and water, and offer the possibility of increasing the efficiency of the solar-to-hydrogen pathway and lowering the capital cost of the system, but they still require land area to collect sunlight. These systems might allow the use of seawater directly as the feedstock instead of high-purity water (see Figure 7.8).

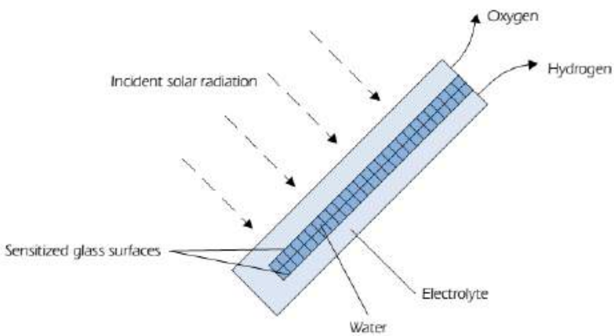

Figure 7.7. Principle of photo-electrolytic cell (IEA, 2006)

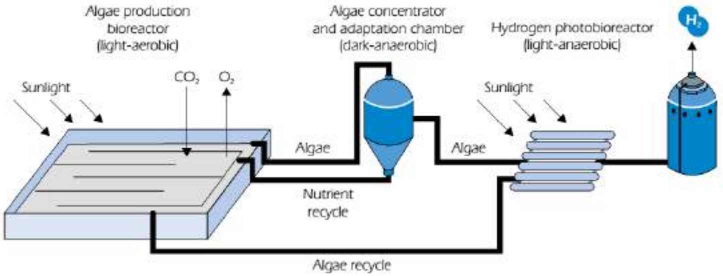

Figure 7.8. Principle of photo-biological hydrogen production (IEA, 2006)

7.3.2 Environmental impact

Hydrogen can help reduce CO_2 in the atmosphere, especially if it is used as energy source for vehicles instead of the conventional fossil fueled ones. According to the report by the International Energy Agency in 2011, the transportation sector is responsible for 23% of the worldwide CO_2 emissions from fossil fuel combustion (great majority for cars and trucks). It is predicted that the global demand for road transport will rise for 40% by 2035. The vehicles powered by hydrogen fuel cells can significantly reduce GHG emission considering that the only by-products are heat and water. The National Academy of Sciences predicts that 2 million hydrogen vehicles could be on the road in 2020, growing to 25 million vehicles by 2030. This would lead to reduction in GHG emissions for light-duty vehicles of 20% until 2035 and even more than 60% by 2050. Although the fuel cells itself do not emit CO2, these vehicles are not completely „green" since the hydrogen production technologies are responsible for some GHG emissions. Two common methods, natural gas steam reforming and coal gasification, both release CO_2 during the extraction process. However, even when the emissions from fuel production are taken into account, hydrogen fuel still emit significantly less amount of GHG comparing to fossil fuels (petroleum fueled cars).

The recently published research shows that fuel cell vehicles using hydrogen produced from natural gas reduce total GHG emissions by 60% compared with the conventional gasoline-powered internal combustion engine vehicles. Of course, this percentage is even higher if the less carbon-intensive technology is used for hydrogen production. When hydrogen is produced using electrolysis technology powered by renewable sources, there is little or no GHG emitted, making it one of the most environmentally clean sources of fuel. When produced with renewable energy, hydrogen's total greenhouse gas emissions from production to use in a fuel cell vehicle are lower than total emissions from traditional gasoline, biofuels, or hybrid-powered vehicles. To reduce CO_2 emissions, scientists are working on extracting hydrogen with methods that use carbon capture and storage (CCS) technologies, which capture, transport, and store carbon dioxide emissions before they are released into the air. With CCS, the CO_2 produced by hydrogen production is transported to a storage site and then injected under high pressure into deep underground caverns, where it cannot escape into the atmosphere and contribute to global warming. Using these technologies makes hydrogen production more environmentally friendly. Combining CCS with coal gasification enables affordable hydrogen production with low GHG emission.

During this process, the coal is being turned into gas that, among other elements, contains hydrogen. The hydrogen is then extracted in several steps. With CCS the CO_2 emissions are reduced by as much as 90% comparing to coal-fueled power plant. However, some scientists claim that hydrogen power right now is not as clean as it sounds. In addition to the potential GHG emission during hydrogen production, hydrogen itself may pose a danger to the atmosphere. It is impossible to manufacture, store, and transport hydrogen without some escaping into the atmosphere. As more hydrogen is used, escaped hydrogen could accumulate in the atmosphere, depleting the ozone layer and contributing to global warming. Scientists have tried to develop more environmentally friendly methods of producing hydrogen. So far, none of these has gone beyond computer models and research labs. For example, hydrogen produced via electrolysis that uses renewable sources of electricity like wind or solar power has zero or near-zero greenhouse gas emissions and is very attractive in theory. Yet less than 5% of hydrogen today is actually produced using this method. This does not seem likely to change in the near future, since there are currently no commercial scale demonstrations of zero-emission hydrogen-production plants running.

References

Antonio, F de O. (2010). Wave energy utilization: A review of the technologies. *Renewable and sustainable energy reviews, 14*(3), 899-918.

Council, World Energy. (2016). World Energy Resources 2016.

Esteban, Miguel, & Leary, David. (2012). Current developments and future prospects of offshore wind and ocean energy. *Applied Energy, 90*(1), 128-136.

Frid, Chris, Andonegi, Eider, Depestele, Jochen, Judd, Adrian, Rihan, Dominic, Rogers, Stuart I, & Kenchington, Ellen. (2012). The environmental interactions of tidal and wave energy generation devices. *Environmental Impact Assessment Review, 32*(1), 133-139.

Inernational Energy Agency (IEA), (2006), Hydrogen Production and Storage

Web page (2017) retreived from http://www.alternative-energy-tutorials.com/wave-energy/wave-energy-devices.html

Leveque, Francois, Glachant, Jean-Michel, Barquin, Julian, von Hirschhausen, Christian, Holz, Franziska, & Nuttall, William J. (2010). *Security of Energy Supply in Europe. Natural Gas, Nuclear and Hydrogen*: Edward Elgar.

Pelc, Robin, & Fujita, Rod M. (2002). Renewable energy from the ocean. *Marine Policy, 26*(6), 471-479.

Rourke, Fergal O, Boyle, Fergal, & Reynolds, Anthony. (2010). Tidal energy update 2009. *Applied Energy*, *87*(2), 398-409.

Tabak, John. (2009). *Natural gas and hydrogen*: Infobase Publishing.

CHAPTER 8

GEOTHERMAL ENERGY

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Abstract: Geothermal energy has very significant potential and considering that the earth constantly emits heat, it can be found all over the world. Due to the different temperature levels available, geothermal energy can be used for power generation and for various other heat demands. Heat sources are contained in water (low, moderate or high temperature levels) or in soil (hot rocks). High temperature water (or steam) from the springs can be used for electricity production, moderate temperature water can be directly applied for heating or in industrial purposes, while heat from low temperature water and soil are mainly used as a heat source for heat pumps. Some widely used or promising technical solutions are explained. Environmental effects of geothermal energy use are discussed.

Learning objectives:

After mastering this chapter, the student will have the ability to:

- Understand the potentials and availability of geothermal energy

- Understand and discuss potential environmental impacts of geothermal energy application
- Critically discuss the questions related to the possible use applications of geothermal energy

Geothermal energy represents remnant heat derived from the formation of the planet 4.5 billion years ago (approximately 40%), as well as heat from the radioactive decay of naturally occurring radioactive isotopes (remaining 60%) (Glassley, 2014). Thermal energy in the earth is contained in the rocks as well in the natural fluid in its fractures and pores at different temperature levels (Leveque et al., 2010). In history the warm geothermal fluids have been used for cooking and bathing, but at the beginning of 20th century this renewable energy source found its wider industrial and commercial application, such as electrical power generation. The average heat flow through the Earth`s crust is nearly 59 mW/m^2. For most of the continental areas, the heat flow is caused by two elemental processes: the heat convection and conduction from the Earth's mantle and core, and heat generated by the decay of radioactive elements (isotopes of uranium, thorium, and potassium) in the crust. In regions with volcanic or tectonic activities there is higher heat flow registered, which is the reason why people usually relate geothermal energy only with these places, such as Iceland, New Zealand, Japan, Yellowstone National Park (recent volcanism). It is often neglected that there are opportunities to use geothermal energy source in many other regions as well.

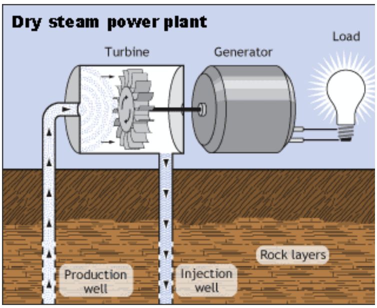
For generating electricity, it is necessary to drill to the depths where heat can be found at high-temperature levels (in the range 150°C to 200°C). For other heating applications it is sufficient to reach lower temperatures of 100°C to 150°C. Geothermal heat can be used directly and indirectly to heat and cool buildings, reducing electrical demand for heating, ventilation, air conditioning and cooling (HVAC) (Glassley, 2014). Even at temperatures less than 50°C, geothermal energy can be used for various purposes. Geothermal heat pumps are most common used technology that uses low-grade energy that can be easily reached at depths between 2 and 200m for heating and cooling in buildings, significantly reducing electricity costs. Although the temeratures in soil near to the earth surface depend from outside weather conditions, the temperatures at depths more than 3 meters are nearly constant due to the constant heat flow from interioir of the earth. One of the prominent features of geothermal heat pumps, comparing to air to water heat pumps, is its constant efficiency thorough the whole year (does not vary with outside air temperature). Geothermal energy has several prominent features: it requires no external fuel infrastructure, considering that the heat never stops being supplied from the earth's interior. The greenhouse gas emissions for electricity production comparing to fossil-fueled power plant are reduced by more than 90%, or completely eliminated. This energy source occurs in diverse ways, making it possible to use for different purposes. The mid-temperature level geothermal heat can be directly used for food processing, drying materials, agricultural activities and greenhouses, aquaculture and paper manufacturing. Although these direct-use applications have been developed and proven to be very successful, they are still relatively unknown and vastly underutilized. The most effective use of geothermal energy can be found where available source and technology match the needs of the observed energy sector. Combined heat and power in cogeneration and hybrid systems, as well as heat pump applications, are options that offer improved energy savings (Leveque et al., 2010). Many attributes of geothermal energy, namely its widespread distribution, base-load dispatchability without storage, small footprint, and low emissions, are desirable for reaching a sustainable energy future. Geothermal is one of the few renewable energy resources that can provide continuous base-load power with minimal visual and environmental impacts. These systems have a small footprint and virtually no emissions. Having a significant portion of the base-load supplied by geothermal sources would provide a buffer against the instabilities of gas price fluctuations and supply disruptions.

8.1 Geothermal power production

The main feature of the geothermal power plants is that they are typically designed as baseload power plants. This differentiates them from other renewable sources, like wind and solar, that is highly intermittent. Consequently, due to the interrupted (and often unpredictable) power generation form solar or wind, these facilities cannot provide solid base-load capacity. It is the baseload power which sustains most infrastructure system and needs to be reliable and fueled by a consistent energy source. Considering that geothermal energy never stops being emitted from the earth`s interior makes it great choice for energy source for the base-load power plant. The first production of electricity from geothermal steam was installed in Larderello, Italy, in 1904. (Leveque et al., 2010). Since that time, other hydrothermal developments, such as the steam field at The Geysers, California, the hot-water systems at Wairakei, New Zealand, Mexico, Reykjavik, Iceland, Indonesia and the Philippines, have contributed to the total installed electrical generating capacity of nearly 10,000 MWe at the beginning of the 21st century, while direct-use capacity is more than 100,000 MWt (thermal MW) (Glassley, 2014). Another important feature of geothermal power generation is that it requires no external fuel infrastructure. Since this energy source is naturally occurring near the powerplant, there is no need for fuel transportation, which makes it economically and environmentally desirable. Recent studies have shown that geothermal power generation can also be flexible. For a resource to be flexible, a power generator requires that the power output from the generating facility be able to increase or decrease as demand for power changes through the day and as the power input to the grid changes. Flexible generation requires additional design components and operational strategies that are still in the process of being fully implemented. As currently applied, flexible generation is accomplished by varying the amount of hot geothermal fluid that is introduced to the power generating equipment, either through bypassing the generation equipment through the use of secondary piping circuits or by throttling the rate at which geothermal fluid is extracted from the reservoir. Producing power from geothermal energy relies on the ability to convert geothermal heat at depth to electricity. The equipment necessary to accomplish this is a piping complex that will bring hot fluids from depth to a turbine facility on the surface where the thermal energy is converted to kinetic energy in the form of a rotating turbine. The kinetic energy of the turbine is then converted to electrical energy using an electrical generator.

For a geothermal site to be useful, it must have the capacity to produce steam at a sufficiently high rate to make generation of electricity economically feasible. Although conditions such as construction costs, exploration investment, access to electrical infrastructure, and other considerations have a large effect on the economic viability of a site, it is generally considered that a site needs to be capable of generating more than a MW of power in order to be used for the power transmission infrastructure. If the application is planned to be local, such as power for a small community, a few industrial buildings, or a university campus, much smaller units (few tens of kW) can be economically employed. The geothermal resource must be evaluated in terms of pressure and wellhead of the source, as well as its relationship with the fluid flow rate through the turbine. Dry steam systems are rarely found, but they are capable to supply significant power generation. One successful example is the Geysers in California (Figure 1), with current installed capacity of approximately 1400 MW, of which 933 MW is in operation. That makes it the world's largest geothermal power generation site, with additional generating capacity under development. Larderello, in Italy, is the only other operating dry steam facility in the world.

This process is accomplished using production wells that penetrate hundreds to thousands of meters into the subsurface, providing a low path for the reservoir fluid to ascend from depth. Injection wells are used to replenish the reservoir by recycling condensed water, supplementing it (if needed) with other water sources. There are several types of reservoirs. Dry steam reservoirs have sufficient enthalpy to vaporize all available water. Such systems are the simplest to engineer and have the highest energy availability of all geothermal resources but they are geologically uncommon (see Figure 8.1).



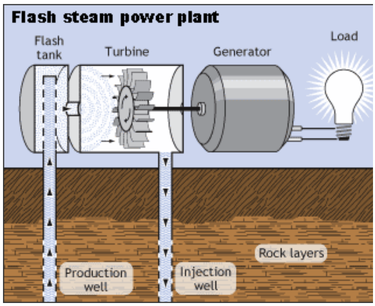
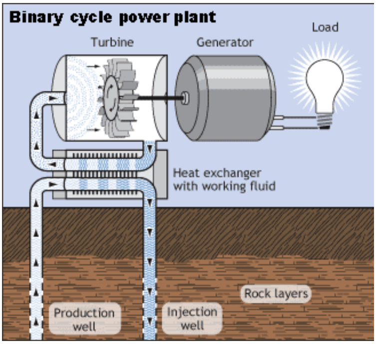


Figure 8.1. Dry steam power plant (www.energy.gov)

Figure 8.2. Flash steam power plant (www.energy.gov)

The other more common, hydrothermal systems usually possess sufficient heat (temperatures in the range of about 160°C–250°C) at elevated pressures to allow water to flash to steam as it approaches the turbine (see Figure 8.2). When the steam cools, it condenses to water and is injected back into the ground to be used again. Power is generated in dry steam and hydrothermal power generating plants by the expansion of the steam as it expands and cools in a turbine facility designed to extract as much energy from the fluid as efficiently as possible. Lower temperature geothermal resources can be used to generate power using binary plants that employ a working fluid (usually an organic compound such as isopentane or propane, or an ammonia–water solution) that has a boiling temperature significantly below that of water. In a binary plant, the geothermal water flows through a heat exchanger, transferring its heat to the working fluid, and is then reinjected into the reservoir (see Figure 8.3). Binary plants are becoming the fastest growing part of the geothermal energy market. They have the advantage of requiring lower temperature resources, they emit no gases to the atmosphere, and they can be built in modular form.

(Leveque et al., 2010) Today, with nearly 10,000 MWe of electricity generated by geothermal worldwide, there are several energy conversion technologies commercially available at various stages of maturity (direct steam expansion, single and multistage steam flashing, organic binary Rankine cycles, two-phase flow expanders). There are inherent limitations on converting geothermal energy to electricity, because of the lower temperature of geothermal fluids in comparison to much higher combustion temperatures for fossil fuels.



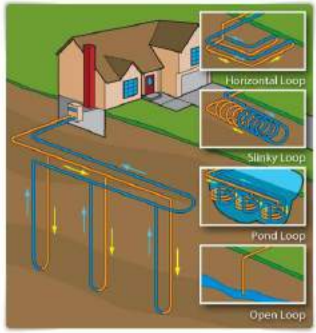


Figure 8.3. Binary cycle geothermal power plant (www.energy.gov)

Figure 8.4. Geothermal heat pump (http://www.dustymars.net/heat-pump-geothermal/)

Lower energy source temperatures result in lower maximum work-producing potential in terms of the fluid's availability or exergy; and in lower heat-to-power efficiencies as a consequence of the Second Law of thermodynamics. The value of the availability determines the maximum amount of electrical power that could be produced for a given flow rate of produced geofluid, given a specified temperature and density or pressure. Current practice for geothermal conversion systems shows utilization efficiencies typically range from 25% to 50%. Future engineering practice would like to increase these to 60% or more, which requires further investments in R&D to improve heat-transfer steps by minimizing temperature differences and increasing heat-transfer coefficients, and by improving mechanical efficiencies of converters such as turbines, turbo-expanders, and pumps.

Geothermal heat pumps

Geothermal heat pumps are using the low-temperature geothermal heat that can be found in the relatively shallow subsurface (<300 m depth). The constant heat flux from the interior of the earth together with the solar flux to the soil makes it energy source with relatively constant temperature during whole year. This is very important in terms of efficiency (heating capacity and COP of air to water heat pumps significantly decreases with lower ambient temperatures). The currently available geothermal heat pump technology provides the COP values in the range of 3–5, making them the most energy efficient plant for HVAC purposes. The sizing and design of these systems are well-known and developed in practice, but it is crucial to adequately investigate properties of the geothermal source and to link it with the requirements of the building systems (see Figure 8.4) .

Direct use of geothermal energy

Unlike geothermal power generation, where heat is converted to electricity, direct-use applications involve introducing heat energy directly in some process. Geothermal energy with temperatures in the range of 10°C−150°C can provide the heat necessary for broad range of industrial needs.

As of 2010, approximately 122 TWh/yr of thermal energy was used for direct-use purposes worldwide, which was derived from an installed capacity of 50,583 MW(Lund & Boyd, 2016). The growth in installed capacity of direct-use applications reflects a rapid growth in international development of this type of system. In 1985, 11 countries reported using more than 100 MW of direct-use geothermal energy. In 2010, that number had increased to 78. The summary of the various categories of direct-use is shown in Table 8.1, while the comparison of the energy utilization for years 1995-2015 can be seen in Figure 8.5.

Table 8.1. Summary of the various categories of direct-use of geothermal worldwide for the year 2015. (Lund & Boyd, 2016)

	Capacity [MWt]	Utilization [TJ/year]
Geothermal heat pumps	50,258	326,848
Space heating	7,602	88,668
Greenhouse heating	1,972	29,038
Aquaculture pond heating	696	11,953
Agricultural drying	161	2,030
Industrial uses	614	10,454
Bathing and swimming	9,143	119,611

Cooling/snow melting	360	2,596
Others	79	1,440
Total	**70,885**	**592,638**

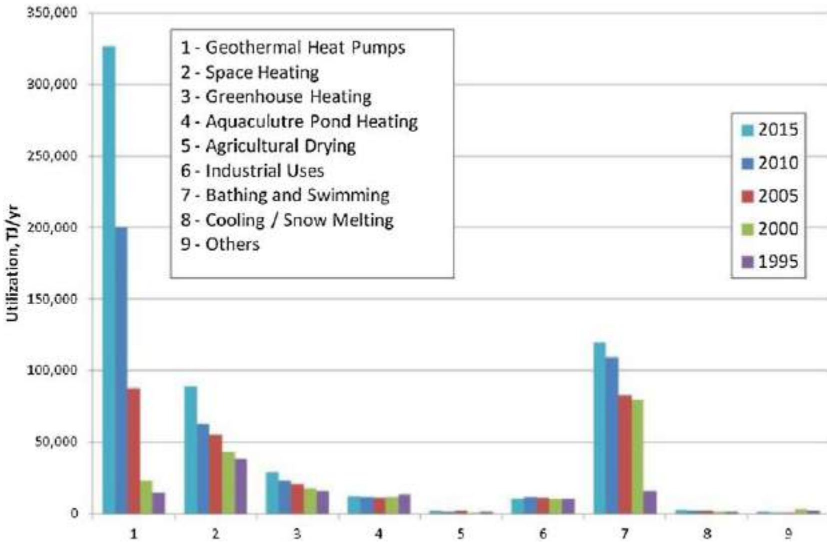


Figure 8.5. Comparison of worldwide direct-use geothermal energy in TJ/year from 1995, 2000, 2005, 2010 and 2015. (Lund & Boyd, 2016)

Each direct-use application system must be evaluated in detail for heat losses, demand load, and the magnitude of the potential geothermal heat supply. More efficient use of these low-to-moderate temperature resources can be increased by combining several applications in a cascade way. Such systems allow the maximum amount of heat to be used for useful work. One of the main advantages of the geothermal direct-use applications is that they significantly reduce or completely eliminate the energy consumption usually coming from fossil fueled systems. They also have a high capacity factor and reduce fire risk by eliminating the need for combustion, so they can provide significant benefits over traditional technologies. They also significantly reduce greenhouse gas emissions.

District heating

In 2010, space heating accounted for 63,025 TJ/yr of the total 423,830 TJ/yr energy consumed through direct-use applications, while in 2015 it was 88,688 TJ/yr of the total 592,638 TJ/yr. That is the third largest application purpose of the direct-use of geothermal energy worldwide (Figure 5). These space heating applications usually involve district heating network that supplies the buildings with necessary heat. The system comprises of geothermal heat source, piping network, control system and disposal or reinjection system. If the temperature of the geothermal fluid is high enough (>65°C) then the hot water extracted form shallow well or spring is directly introduced to system, with direct disposal of the fluid. On locations with moderate temperatures (50°C–65°C) fluid from geothermal source is brought to the heat exchanger that allows the heat transfer in closed loop network. For sites with low temperatures available, using heat pumps is recommended, while these systems require additional energy input.

As part of a European funded study, the "Pan-European Thermal Atlas" has been published online (see Figure

8.6). It shows the different heating options in Europe, with current heat demand, potential for solar energy, biomass and geothermal for district heating. This energy planning tool provides basis for European governments, businesses, consultants, academics, and planners to make informed decisions about investments in energy efficiency measures and use of untapped alternative energy sources for heating and cooling.

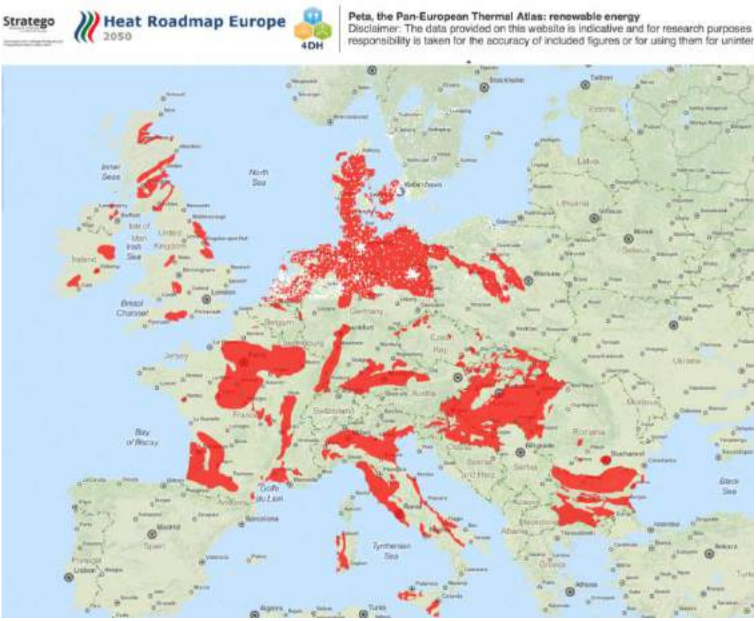


Figure 8.6. Europe thermal atlas (Source: heatroadmap.eu)

Aquaculture

One of the simplest direct-use applications for geothermal fluids is aquaculture. Geothermal fluids can be used to raise various types of fishes and other species such as catfish, bass, mullet, eels, salmon, trout, tropical fish, lobsters, alligators, algae, prawns, shrimp, mussels, scallops, etc. Geothermal heat is used to optimize the temperature for breeding, growth, and health of the species of interest.

Drying

Geothermal heat is often use for drying food products, such as onions, meat, fruit, potatoes, spices, sugar, but also materials like lumber, concrete blocks and many other. Using geothermal heat for this purpose bring savings in fuel comparing to the conventional fossil fuel fired boilers. Since there is no combustion, there are no risks of fire. In addition, combined heat and power in cogeneration and hybrid systems, and as a heat source and sink for heat pump applications, are options that offer improved energy savings.

8.2 Environmental impact of using geothermal energy

The results of analysis of full life cycle of geothermal energy systems show that their environmental impact is significantly lower compared to the conventional power plants (Leveque et al., 2010). Considering that this renewable energy source is located underground, while the equipment of these systems is relatively compact, their overall impact on surroundings is small. The GHG emissions is minimal. The availability and consistency of the geothermal energy enable it to be reliable base-load plant source, so there is no need for any storage or back-up systems. This source does not need to be produced in one location and then distributed over great distance, so comparing to fossil or biomass there are significant savings. These savings refer not only to transportation costs, but also to savings in GHG emissions emitted during transport. There are minimal discharges of nitrogen or sulfur oxides resulting from its use, and there is no need to dispose radioactive materials. The general conclusion from all recently published studies is that emissions and other impacts from geothermal plants are dramatically lower than other forms of electrical generation (Tester et al., 2006). The environmental impact of ground-source heat pumps is quite limited because they are usually installed during building construction and normally utilize a subsurface heat exchanger, buried well below the frost line. However, there are some potential impacts that should be evaluated and analyzed prior to more widespread use of geothermal energy. Some of the major concerns are related to induced seismicity or subsidence, water use and contamination. Issues of noise, safety, visual impacts, and land use associated with drilling and production operations are also important but fully manageable. There are several potential environmental impacts from any geothermal power development, and they include: gaseous emissions, water use and pollution, solids emissions, noise pollution, land use and subsidence, induced seismicity and landslides, disturbance of natural wildlife habitat and vegetation, altering natural vistas and potential catastrophic events. Despite this long list, current and near-term geothermal energy technologies generally present much lower overall environmental impact than the conventional fossil-fueled and nuclear power plants.

Gaseous emissions

Geothermal steam and flash plants emit much less CO_2 per MWh comparing to fossil-fueled power plants, while binary plants practically have no CO_2 emission. The concentrations of regulated pollutants – nitrogen oxide (NOx) and sulfur dioxide (SO_2) – in the gaseous discharge streams from geothermal steam and flash plants are extremely small. Recently published data indicate that geothermal plants are far more environmentally benign than the other conventional plants (Tester et al., 2006).

Water pollution

Fluid flows coming from drilling and production can contain dissolved minerals. The amount increases with fluid temperature, so for high-temperature level source (>230°C), it is necessary to investigate it. Some elements, such as boron and arsenic can empoison the soil and water and induce negative impact on local habitats and vegetation. If the system well casing is damaged, these fluids can enter and damage the environment. Therefore, it is necessary to monitor the site in drilling and operating phase in order to avoid any dangerous leakages. Generally, there is very small danger of contamination of the environment since the all the produced fluid is being reinjected (Tester et al., 2006).

Solids emissions

There is practically no chance for contamination of surface facilities or the surrounding area by the discharge of solids from the geofluid. The only possibly dangerous situation could be an accident associated with a fluid treatment or minerals recovery system that would cause spilling of solids in the environment. To be on the safe side, it is advisable to be cautious in cases where it is required that the fluid is chemically treated in order to remove solids. The chemicals used in this process may be toxic and subject to regulated disposal (Tester et al., 2006).

Noise pollution

Noise caused by the geothermal systems operations is nor significantly different from other industrial facilities. The highest noise levels are achieved in drilling, stimulation and testing phase, where these levels are in range of 80-115 dBA. During normal operation of the system, the noise levels at distance of 900 m are not higher than 71-83 dBA. These levels are significantly lower when we move further from the source, so considering that geothermal plants are located in large geothermal reservoir area, there should not be evident problems with noise.For comparison, congested urban areas typically have noise levels of about 70-85 dBA, while living close to a major freeway implies 90 decibels (Tester et al., 2006).

Land use

The impact of the observed geothermal power plant on land strongly depends on the properties of the geothermal fluid and waste stream discharge. Normally, these plants are built on the site near the reservoir, due to the losses of pressure and temperature that can be caused by long pipeline. In order to avoid too big influence on area and to allow farming or other uses of land, the pipelines can be gathered and mounted on pillars and railings. Therefore, the total footprint of the power plant together with the auxiliary equipment is relatively small (Tester et al., 2006).

References

Glassley, William E. (2014). *Geothermal energy: renewable energy and the environment*: CRC Press.

Leveque, Francois, Glachant, Jean-Michel, Barquin, Julian, von Hirschhausen, Christian, Holz, Franziska, & Nuttall, William J. (2010). *Security of Energy Supply in Europe. Natural Gas, Nuclear and Hydrogen*: Edward Elgar.

Lund, John W, & Boyd, Tonya L. (2016). Direct utilization of geothermal energy 2015 worldwide review. *Geothermics, 60*, 66-93.

Tester, Jefferson W, Anderson, Brian J, Batchelor, Anthony S, Blackwell, David D, DiPippo, Ronald, Drake, E, . . . Nichols, Kenneth. (2006). The future of geothermal energy: Impact of enhanced geothermal systems (EGS) on the United States in the 21st century. *Massachusetts Institute of Technology, 209*.

CHAPTER 9

HYDROPOWER ENERGY

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Abstract: The potentials and current state of the hydropower use is elaborated. There is a variety of different hydro-power plants, while the main categories are: reservoir-type, run-of-river systems, pumped storage and small scale hydropower systems. The technology of different types is explained. The mostly used turbines in hydro-power plants are: Impulse turbine (Pelton, Cross Flow) and Reaction turbine (Propeller, Frances, Kinetic). Environmental impact of Hydro-power plants is elaborated, highlighting the difference between large-scale plants, that are no longer considered „green“and small-scale hydropower.

Learning objectives:

After mastering this chapter, the student will have the ability to:

- Understand the potentials and availability of hydropower energy for electricity production
- Discuss the advantages and disadvantages of hydropower production (economic, social and environmental aspect)

- Understand and discuss potential environmental impacts of hydro-power systems (both large-scale and small-scale)
- Critically discuss the questions related to the possible use of hydropower (systems types, turbines used)

Hydropower is a mature technology that is currently used in about 160 countries for producing electricity. With a total capacity of approximately 1,060 GWe (19.4% of the world's electric capacity in 2011), hydropower generates about 3,500 TWh per year, which is equivalent to 15.8% of 2011 global electricity generation. Hydro-power plants provide at least 50% of the total electricity supply in more than 35 countries. One of their advantages is that they provide flood control and irrigation. Using hydropower to produce electricity is very cost-effective. It offers high efficiency with low operating and generation costs, although the initial investment cost is significant. Another key feature is the operational flexibility. The capacity of hydropower plants can be varied in range 23%-95%, depending on targets and the service (i.e. baseload, peak load) of the specific power plant.

The global technical hydropower potential is very significant, and it is estimated to be around 15,000 TWh per year. Half of this total potential is available in Asia and 20% in Latin America. Large untapped technical potential is still available in Europe, Africa, Latin America and Asia. Even in the most hydropower-developed regions, Europe, there is still about 50% of the unused potential. For small hydropower the potential is estimated to be 150-200 GWe. Only about 20% of this potential has been exploited to date.

However, large hydropower projects can encounter social opposition because of their impact on water availability, ecosystems and the environment, and the need to relocate populations that may be affected by the project. Major hydropower plants issues include public acceptance, high initial investment costs and long payback periods, long approval and construction cycles, and long lead times to obtain or renew concession rights and grid connections. These challenges are likely to limit the implementable hydropower potential. Hydropower systems can be categorized as follows (Egré & Milewski, 2002):

- reservoir-type systems with significant storage capacity;
- run-of-river systems with little or no storage capacity and river diversion systems
- pumped-storage systems;
- small, mini and micro hydropower systems.

Reservoir-type systems

Reservoir systems (see Figure 9.1) involve impounding water behind a dam to enable flow regulation throughout the year (on a daily or monthly basis) or even in some cases on a multi-annual basis for very large reservoirs. The reservoir also provides a reserve of energy to satisfy electricity demand during dry seasons and/or periods of peak demand.

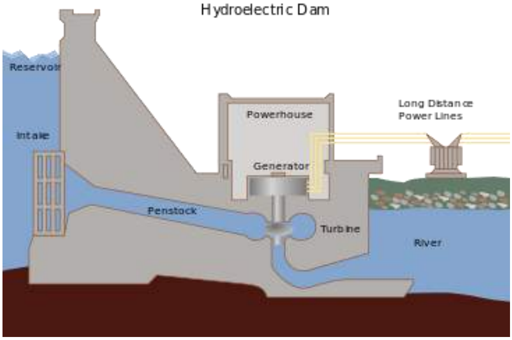

Figure 9.1. Reservoir-type Hydropower (https://en.wikipedia.org)

The environmental impacts of reservoir type systems originate from:

- the construction activities involved in building the dam, dikes, embankments and power plant;
- the presence of infrastructure (access roads, power lines, substations, etc.);
- the changes in river flow patterns;
- the creation of a reservoir, possibly generating major ecological changes from terrestrial and river environments to a lake-type environment, but also land use transformations, such as resettlement of communities and of production activities.

Run-of-river hydropower systems

This type of hydropower generation utilizes the flow of water within the natural range of the river, without necessity of a reservoir (or with little one). They can be designed with small head, generally on large rivers with gentle gradients, or with high head, usually on small rivers with steep gradients. Run-of-river projects (see Figure 9.2) can use all the river flow or only a fraction of it. The amount of power produced by run-of-river systems that use all the river flow may vary considerably throughout the year since it depends on the river discharge. Most run-of river plants are therefore conceived so as to provide the same power output all year long for the base demand, using only a fraction of the total river flow. A common strategy to optimize the energy output of hydropower plants on a river is to build a large storage reservoir in the upper catchment, which will even out flow for several run-of-river or smaller reservoir plants downstream. In all run-of-river projects, the absence of any sizable reservoir helps limit considerably both the social and the environmental impacts, as the river is not transformed into a lake. Furthermore, the flow pattern of the river remains essentially unchanged, which reduces downstream impacts of the powerplant.

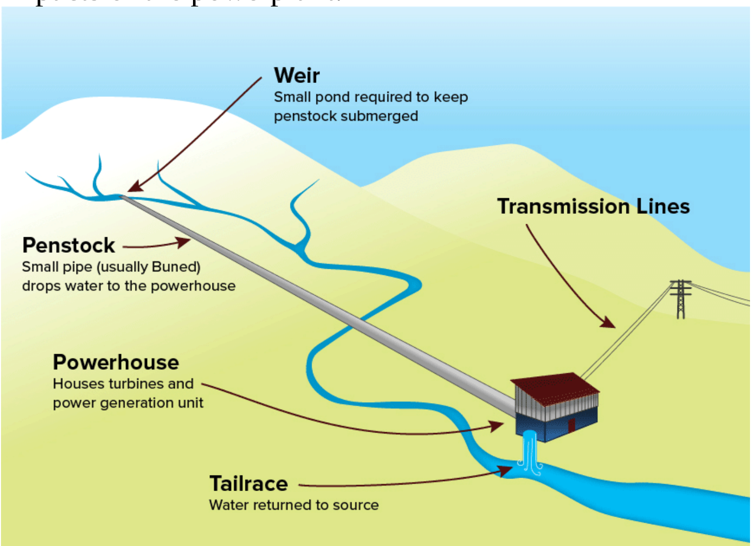

Figure 9.2. Run-of river hydropower diagram (http://nextgenerationhydro.ca/resource-centre/hydro-basics/)

River diversion hydropower systems

River diversion consist of:

- In-stream diversion: A river is dammed and the water flow is diverted through tunnels into the mountain side to discharge further downstream back in its riverbed.
- Cross-watershed diversion: This strategy will increase the flow of the receiving river where the power plant is located, and decrease the downstream flow of the diverted river.

With in-stream diversions, the goal is to increase the head of the power plant, thereby increasing available power and energy. For cross-watershed diversions, the result is an increase in energy, this time by increasing the flow of the receiving stream where the power plant is located. The specific environmental impact of diversion hydropower systems is a severe or total reduction of flow immediately downstream of the diversion. This can affect downstream shore erosion, water temperature and water quality. The magnitude of such impacts is a function of ecosystems affected, particularly in terms of aquatic biology, and the length of the river section with diminished flow. In cross-watershed diversions, an additional impact has to do with the increased flow in the receiving river. There is also a risk of spreading unwanted species, fish or plants, between catchments.

Ultimately, a new ecological equilibrium appears, with colonization of the river edge by plants, shrubs and terrestrial fauna in diminished flow rivers, and an increase in water habitats in increased flow rivers. The most effective measure is to ensure a minimum ecological flow downstream of a diversion, in order to maintain a river habitat and existing land uses downstream (fishing, navigation, urban and industrial water supply, etc.). The flow of most natural rivers varies significantly from season to season, and some rivers dry up completely during parts of the year. The ecosystem of each river has adjusted over time to the flow pattern of the river. The design of an ecological flow in a diverted river may be based on the habitats of the most valued aquatic species in the river, in order to minimize the losses of spawning grounds, for example. In a river with reduced flow, small weirs can be built to ensure a water level similar to pre-diversion conditions.

Pumped-storage hydropower systems

Pumped-storage plants (see Figure 9.3) pump water into an upper storage reservoir during off-peak hours by using surplus electricity from base load power plants. They reverse flow to generate electricity during the daily peak load period. They are considered to be one of the most efficient technologies available for energy storage. The concept of pumping water back to the upper reservoir during off-peak hours means that these plants are net energy consumers: it takes more power to pump water up to the top reservoir than is produced by the plant when the water rushes down to the lower reservoir. Generally, from 65% to 75% of the electricity required by the pumping is recovered during the generation phase.

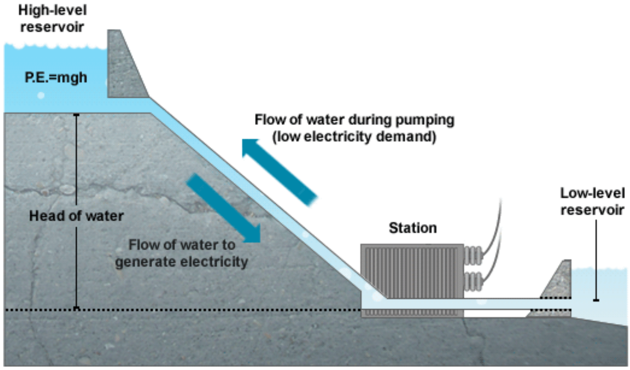

Figure 9.3. Pumped storage hydropower system (http://energystoragesense.com/pumped-hydroelectric-storage-phs/)

Developing pumped-storage plants is cost effective when other plants in the grid produce mainly base energy with little flexibility, such as coal power plants and/or nuclear stations. In such cases the cost of peak electricity can be twice as much or more than the cost of off-peak electricity. A small upper pool which empties very quickly on short intervals, once or twice a week, characterizes pumped storage plants. The drawdown in the upper reservoir is therefore very significant. These pools are often manmade and do not develop into a stable aquatic environment. Pumped-storage plants sometimes can use a river, a lake or an existing reservoir as the lower reservoir, or to create additional pool. The environmental issues associated with pumped storage plants are mostly related to the siting of the upper pool, the powerhouse location (underground or above ground) and the nature of the lower reservoir ecosystem. These issues are essentially site-specific and can be addressed during the design phase of the project.

Small, mini and micro hydropower systems

The definitions of small, mini and micro-hydropower systems are relative and vary depending on the circumstances of each country. Therefore, no definitions exist which are generally accepted all over the world. Compared to large projects, small-scale plants benefit in terms of ease of introduction, as the period for planning and construction is shorter, investment is smaller and only small areas need to be acquired. Small-scale hydropower is often used for distributed generation applications as an alternative to, or in combination with, diesel generators or other small-scale power plants for rural applications.

Environmental impacts are roughly proportional to area inundated. There are also benefits related to reduced safety risks associated with small dams, and lesser population. From an environmental standpoint, the distinction between renewable small dams and non-renewable large dams is somewhat arbitrary. It is not size that defines whether a project is renewable and sustainable or not, but the specific characteristics of the project and its location. The question that rises is: What is less damaging for the environment? One very large power plant, on one river, with an installed capacity of 1000MW, or 200 small hydropower plants of 5MW on 100 rivers? Could the overall impact of a single 1000MW project be less than the cumulative impact of 200 small hydropower projects of 5MW, because of the number of rivers and tributaries which will be affected? Although it is obvious that a smaller human intervention on a specific habitat has fewer impacts than a very large intervention on the same habitat, one should compare hydropower projects based on the energy and power produced. From this standpoint, the cumulative impacts of a multitude of small hydro projects might be larger than those of a single project, given the diversity of ecosystems that may be affected and the much larger cumulative surface area to be inundated for equivalent storage volume with small projects.

The main **advantages** of hydropower production (Okot, 2013):

- Economic aspects
  - It has low operating and maintenance costs
  - It has a long-lasting and robust technology: systems can last for 50-years or more without major new investment
  - It is a reliable source of energy
  - It promotes regional development, creates employment opportunities
  - It uses the proven, well-known technology with highest efficiency

- Social aspects
  - Improves standard of living
  - Leaves water available for other uses
  - Frequently provide flood protection
  - May enhance navigation conditions
  - Enhances accessibility of the territory and its resources

- Environmental aspects:
    - Produces no atmospheric pollutant and only very few GHG emissions
    - No waste is produced
    - Avoids depleting of non-renewable fuel resources
    - Slows down climate change

The main **disadvantages**:

- Economic aspects
    - High capital cost
    - Requires multidisciplinary involvement
    - Long-term planning and long-term agreement are required

- Social aspect:
    - May lead to resettlement
    - Damming of large area reduce public access. It affects outdoor recreation activities
    - The power lines can change the landscape
    - Management of water uses is needed

- Environmental aspect
    - Barriers for fish migration and entrainment
    - Involve modification of aquatic habitats
    - Requires management of water quality
    - The populations may need to be monitored
    - Damming areas rich in biodiverse flora results in carbon emissions

Figure 9.4 shows components of a simplified hydropower scheme (Okot, 2013):. The basic hydropower principle is based on the conversion of a large part of the gross head,

H_g (m) into mechanical and electrical energy. Hydro turbines convert the water pressure into mechanical power which can then be used to drive generator or other machine. The produced power is proportional

Water pressure is converted by hydro turbines into mechanical shaft power. The mechanical shaft power can be used to drive an electrical generator or other machinery. The available power is directly proportional to the product of pressure head and volume flow rate. Generally, the hydraulic power P_o(kW) and the corresponding energy E_o (kWh) over an interval of time

Δt(h) are

$$P_0 = \rho g Q H$$

$$E_0 = \rho g Q H \, \Delta t$$

Where ρ is density of water (kg/m^3) and g gravity (m/s^2). The final power P delivered to the network is given by $P = \eta P_o$, where η is the hydraulic efficiency of the turbo-generator. Hydro is still the most efficient way to generate electricity. Modern hydro turbines are capable of converting up to 90% of the available energy into electricity, although this reduces with size. Micro hydropower systems tend to be in the range of 60–80% efficiency.

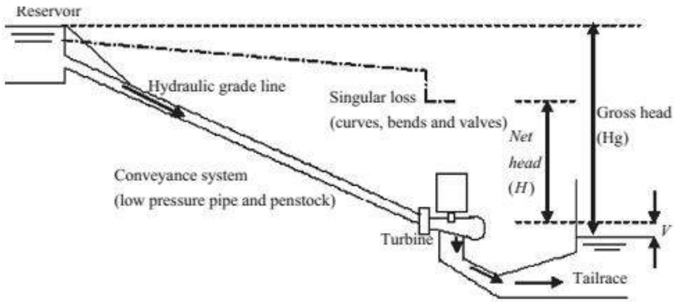

Figure 9.4. Components of a hydropower scheme (Okot, 2013)

Water turbines

Currently, there are various designs of water turbines in use, while each has its own advantages and disadvantages and optimal operation range. Considering that the turbine power output depends on combination of head, water volume and water pressure on blades, it is necessary to adequately select the most suitable turbine type for the selected installation. The most use turbines can be divided into:

- Reaction Turbine Design – the blades are enclosed in a pressurized casing and totally submersed in water. The pressure difference across adequately profiled blades causes the blades to rotate fast.
- Impulse Turbine Design – the water flow hits the turbine blades from one or more jets of water (nozzles). The mechanical power output from an impulse turbine is derived from the kinetic energy of the water flow.

Besides by the type of operation, turbines can be categorized by the design, structure and layout of the blades. Pelton, Turgo or Kaplan Turbines are named after their inventors. The difference between higher and lower elevations of water (where the potential energy is stored) is the head of the system. Generally, in hydro energy and hydro-electric power systems, a low-head means a vertical distance of less than 30m, a medium-head means a vertical distance of between 30 to 150m, while a high-head means a vertical distance greater than 150m.

The **Pelton Water Turbine** (**Pelton Wheel)**, named after its inventor Lester Pelton, is the most often used open type turbine wheel design (see Figure 9.5). It is an impulse turbine which is most suitable for high head and low waterflow. Along the perimeter of the wheel there are small curved cups (buckets). High speed water jet injected through the nozzles hits these cups an induces an impulse force which makes the turbine rotate. The most important component of the Pelton wheel is the bucket, that is split in two halves, where each half is turned and deflected back. The special shape makes the jet turns almost 180 degrees.

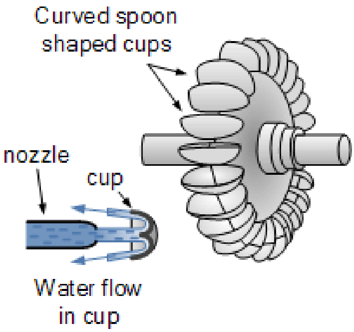

Figure 9.5. Pelton Turbine (http://www.alternative-energy-tutorials.com)

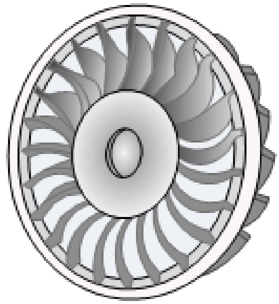

Figure 9.6. Turgo Turbine (http://www.alternative-energy-tutorials.com)

The potential energy generated by the water jet is converted into kinetic energy through these nozzles and nearly all of the energy of the moving water goes into propelling the cups. The jets of water from the nozzles push against the cups of the turbine making the wheel rotate, producing torque and power. The Pelton turbine gains mechanical energy purely due to change in kinetic energy of jet. Depending upon the available water head and number of nozzles positioned tangentially around the wheel, the velocity and direction of the jets of water coming from these nozzles can be controlled to allowing for a constant slower speed which is ideal for electrical power generation. The speed of a Pelton turbine can be controlled by adjusting the flow of water to the cups or buckets through the nozzles.

The **Turgo Water Turbine**, is another impulse type water turbine design where high speed waterjet hits the turbines blades (see Figure 9.6). The difference comparing to the Pelton wheel is that the jet strikes the plane of the bucket at an angle of about 20^o. The curved blades are catching the water and making the turbine shaft rotate. Due to the higher flow rate, a Turgo turbine can have a much smaller diameter wheel than an equivalent Pelton for the same amount of power output allowing them to rotate at higher speeds. However, the Turgo wheel is less efficient than the Pelton wheel.

The **Francis Water Turbine**, named after its inventor James Francis, is a radial flow reaction type of water turbine design in which the entire turbine wheel assembly is immersed in water and surrounded by a casing (see Figure 9.7). The water enters the casing under pressure and is guided through a set of fixed or adjustable slots called guide vanes around the casing which direct the flow of water to the turbines blades at the correct angle. The water enters the turbines blades radially and emerges axially causing it to spin.

A Francis turbine is a submerged turbine similar in design to a propeller turbine that uses water pressure and kinetic energy to rotate the blades. The energy from the flow of the water is transferred to the output shaft of the turbine in form of torque and rotation. This turbine is suitable for low to medium head applications but requires a relatively large quantity of water.

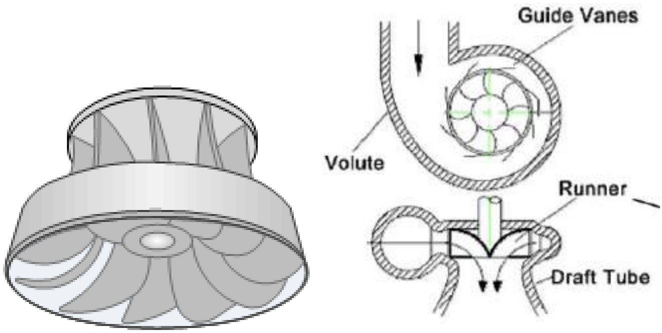

Figure 9.7. Francis Turbine (http://www.alternative-energy-tutorials.com), (Okot, 2013)

The **Kaplan Water Turbine**, named after its Austrian inventor Victor Kaplan, is an axial flow reaction type of water turbine that looks very similar to a ships propeller (see Figure 9.8). It is also referred to as a **Propeller Turbine**. The Kaplan's propeller shaped rotor has two or more fixed or adjustable blades. The operation of a Kaplan turbine is the reverse to that of a ships propeller. The water enters the turbine passage in a radial direction via the inlet vanes. The angle and position of these vanes causes the water to swirl producing a vortex within the enclosed passage applying a force onto the angular shaped propeller blades. As the propellers twisted rotor blades are fixed within this passage to a central shaft, the force of the swirling water pushing against the blades transfers energy to the blades producing a rotation and torque. One of the major advantages of the Kaplan turbine, is that they can be used in very low head applications, providing that there is sufficiently large water flow rates through the turbine, without the need for dams and weirs resulting in a negligible impact on the environment.

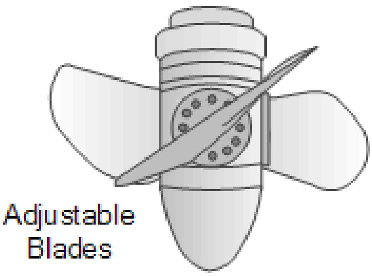

Figure 9.8. Kaplan Turbine (http://www.alternative-energy-tutorials.com)

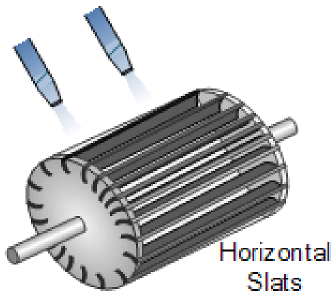

Figure 9.9. Cross-flow Turbine (http://www.alternative-energy-tutorials.com)

The **Cross Flow Water Turbine**, (**Michell-Banki turbine)** is an impulse type water turbine which has a drum-like rotor and uses an elongated, rectangular-section nozzle which is directed against curved vanes (slats) on a cylindrically shaped runner (see Figure 9.9). Cross-flow turbines are less efficient than the modern-day turbines (i.e. Pelton, Turgo, Francis and Kaplan), but it can accommodate larger water flows and lower heads. The water is fed to these slats through a single or double vertical rectangular nozzle to drive a jet of water along the full length of the runner. These nozzles direct the water to the runners and convert the potential energy of the water to kinetic energy. After hitting the first blade, the water drops down through the drum and leaves on the opposite side. Then the cross-flow turbine uses the energy of the water twice, once from above and once from below to rotate the turbine wheel around its central axis providing additional efficiency. The main advantage of the cross-flow turbine is that it maintains its efficiency under varying load and water flow conditions. Also, due to their relatively easy construction, good regulation, and the fact that they can operate with a very low head of water, cross-flow water turbines are ideal for use in mini and micro hydro-power systems. Selecting the best type of water turbine design for the specific situation often depends on the amount of head and flow rate that is available at your particular location and whether it is at the side of a river or stream, or the water is to be channeled or piped directly to the location.

Figure 9.10 gives a basic idea of which particular Water Turbine Design works best according to the available head height and water pressure on the site.

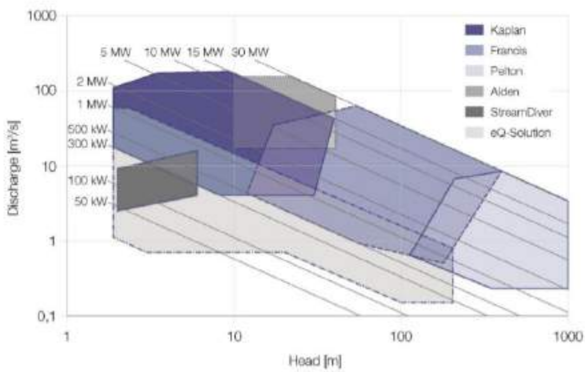

Figure 9.10. Types of small hydro-power by head height, discharge or capacity (Voith, 2013)

9.2 Environmental impact

Large hydropower projects turned out to be controversial because they may: significantly affect water availability over large geographic regions; disrupt natural ecosystems; force the relocation of population groups against their will, require a large electricity transmission infrastructure. These are the main reasons for some ecologists and environmental activists to claim that the large-scale hydropower plants are not so desirable way of producing electricity, as well as not so „green“as it looks like at the first glance. It is evident that hydropower generates numerous economic and social benefits in addition to the electricity produced, such as irrigation, water supply, food control and recreation. Although hydropower development has always been traditionally considered a green energy resource, published reports have differentiated between "small hydro" as being renewable and sustainable, whereas "large hydro" is not (Pang, Zhang, Ulgiati, & Wang, 2015). Since the middle of `70s disruption of sediment transportation, fish migration, downstream flows and estuaries have been carefully observed in various projects. There are number of evidences that the built dams have altered the river waterflow, affecting water temperature, flood extent and nutrition load, that implied consequences on feeding and breeding habitats along the river. Some anti-dam organizations claim that the GHG emissions are similar to the thermal plants of equivalent power. Also, there is inevitable socioeconomic impacts, which involves unwanted moving people from the territory, the extensive destruction of agricultural and forest lands, damages to historical and mineral resources, and the loss of archeological, scenic and tourist sites. Weighing the benefits against the disadvantages is a difficult task for decision-makers. Environmental impacts associated with hydropower use can be summarized in four important categories: fauna, flora, landscape and historical remains. The flora is the most frequently mentioned in recently published studies, due to the evident direct damage caused by the impact of constructing dams on flora, such as agricultural losses, forestry losses, erosion and vegetation. The nature and extent of the impact is highly dependent of site specific characteristics as well as on the type and dimension of hydropower plant (Botelho, Ferreira, Lima, Pinto, & Sousa, 2017). This implies that impacts affecting local communities must be assessed on a case-to case basis. Since the large-scale hydropower is no longer accepted as a clean renewable energy source, small-scale hydropower, whose popularity decreased since the 1960s, can provide possible solution for raised environmental issues and become clean substitute for large hydropower plants. However, small-scale hydropower plants also affect river ecosystems to some extent. These changes of the local ecosystem mainly involve two aspects: disturbances of original landscape and downstream ecosystem degradation caused by impounding and diverting water, which can lead to periodic drying-up of the river. Although hydropower does not consume or pollute the water, it disrupts the natural flow. Since the water flow is the major driver of the river ecological processes, these changes dramatically influence the health of the river ecosystems.

The water sequestration and the periodic drying-up caused by the dam provokes the degradation of the downstream ecosystem services. If it is possible to avoid this, then the impact of the environment is relatively small. The problem could rise if the small-scale power plants are being installed without order on plan in some countries. This can cause both the unstable operation as well as more significant drying-up. Building small hydropower plants on couple of adequately chosen locations may not affect the river noticeably. But extensive application of this technology on every possible site on rivers and waterfalls will dramatically increase the degradation of the environment. Too intensive use of the small-scale hydropower may repeat the environmentally damaging history of large hydropower projects. Significant advances in hydropower technology promise further positive developments. New, less-intrusive, low-head turbines are now being developed for smaller reservoirs, which may increase the investment cost. (Pang et al., 2015). However, the implementation of the necessary advances is often slow and R&D investment insufficient. This is partially due to the misperception that hydropower is a mature technology and offers few upgrading prospects.

References

Egré, Dominique, & Milewski, Joseph C. (2002). The diversity of hydropower projects. *Energy Policy*, *30*(14), 1225-1230.

Okot, David Kilama. (2013). Review of small hydropower technology. *Renewable and Sustainable Energy Reviews, 26,* 515-520.

Pang, Mingyue, Zhang, Lixiao, Ulgiati, Sergio, & Wang, Changbo. (2015). Ecological impacts of small hydropower in China: Insights from an emergy analysis of a case plant. *Energy policy*, *76*, 112-122.

Voith (2013), "Small hydro", Voith, Germany, *http://voith.com/en/Broschuere_SH_final_screen.pdf*.

CHAPTER 10

BIOMASS ENERGY SYSTEMS

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Abstract: Biomass as an energy source is an alternative to fossil fuels (coal, petroleum, and natural gas). In recent years there is a resurgence of interest in biomass energy because biomass is perceived as a carbon-neutral source of energy unlike net carbon-emitting fossil fuels. Bioenergy is also a versatile energy source, since it can be converted into solid, liquid and gaseous fuels. Bioenergy can be used for heating homes, electrifying communities and fuelling the transport sector. In this chapter, different sources of biomass, technical rutes of bioenergy production and environmental impacts in connection with the processes will be discussed in detail.

Learning objectives

- Readers will be informed about different biomass energy sources and distinguish various biomass energy technologies
- Readers will be able to evaluate the environmental impacts of biomass energy use

10.1 Biomass Energy

Biomass is the general term which includes phytomass or plant biomass and zoomass or animal biomass. Biomass contains stored energy from the sun. Plants absorb the sun's energy through photosynthesis and convert it into chemical energy (see Figure 10.1) (Abbasi et al.,2010).

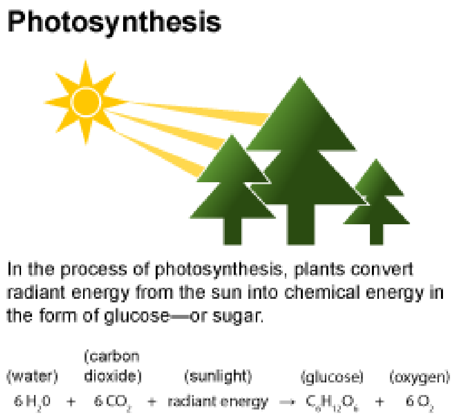

Figure 10.1. The process of photosynthesis (US National Energy Education Project)

The total incident solar energy reaching the surface is 173,000 TW (terawatt), which is 17,000 times what the present day humans consume in fossil fuels (Goldemberg J, Johansson TB, 2004). The energy captured by photosynthesis is about 140 TW which is a very small percentage of the total solar energy reaching our planet, yet the total volume of biomass that is created, is still very large, 10 times our present energy demand. About

100 billion tonnes of carbon is converted to biomass every year (Abbasi et al., 2010).

Biomass as an energy source is an alternative to fossil fuels (coal, petroleum, and natural gas). Burning either fossil fuels or biomass releases carbon dioxide. However, the plants that are the source of biomass capture a nearly equivalent amount of CO_2 through photosynthesis while they are growing. In recent years there is a resurgence of interest in biomass energy because biomass is perceived as a carbon-neutral source of energy unlike net carbon-emitting fossil fuels of which copious use has led to global warming and ocean acidification (US National Energy Education Project).

When biomass is burned, the chemical energy in biomass is released as heat. Bioenergy is a versatile energy source. In contrast to other energy sources, biomass can be converted into solid, liquid and gaseous fuels. Moreover, bioenergy can be used for heating homes, electrifying communities and fuelling the transport sector (World Energy Council, 2016).

10.2 Consumption of biomass energy

10.2.1 Global consumption

Globally, bioenergy (including waste) accounted for 14% of the world’s energy consumption in 2012 with roughly 2.6 billion people dependent on traditional biomass for energy needs (see Figure 10.2) (World Bioenergy Association, 2014).

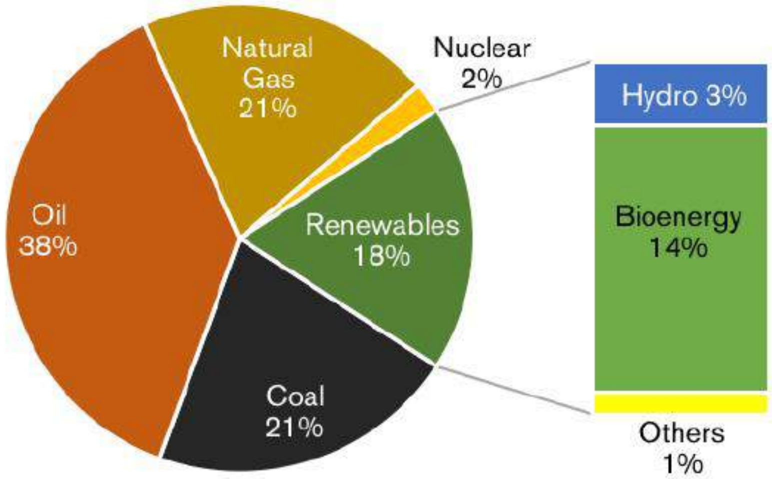

Figure 10.2. Global final energy consumption in 2013 (World Bioenergy Association,2014)

USA and Brazil lead the world in production and consumption of liquid biofuels for transport (accounting for almost 80% of production). In the transport sector, the production of corn ethanol in USA and sugarcane ethanol in Brazil has increased significantly (World Energy Council, 2016).

The use of biomass for electricity is prominent in Europe and North America – predominantly produced from forestry products and residues. The Europe and Americas continent contribute more than 70% of all consumption of biomass for electricity. In the past few years, biomass is seeing increasing uptake in developing countries in

Asia and Africa where significant proportion of the population lacks access to electricity. (World Energy Council, 2016).

Currently, the major use of biomass is in the form of heat in rural and developing countries. About 90% of all the bioenergy consumption is in the traditional use. It includes the use of fuelwood, charcoal, agricultural residues etc. for cooking and heating. This will soon change as rapid urbanisation, inefficient use of biomass leading to deforestation, climate goals and increasing energy demand will lead to a shift towards improved conversion efficiencies and modern bioenergy sources like biogas, pellets, liquid biofuels etc (World Energy Council, 2016).

10.2.2 Consumption in the European Union

In the EU a new consumption record of 93.8 Mtoe was posted in 2015 (Eurobserv'er, 2016). The increase in prodution and consumption of solid biomass was constant in the last two decades (see Figure 10.3).

The total biofuel consumption in EU transport in 2016 was 14,4 Mtoe. Biodiesel part in the total biofuel consumption in EU transport in 2016 was 80,6 %. The aim is to reduce the negative environmental impact of GHG emissions created by producing biofuel, involving indirect land use change. Fuel suppliers also have to reduce the level of greenhouse gas intensity in their fuel by 6% by 2020 (Eurobserv'er, 2017).

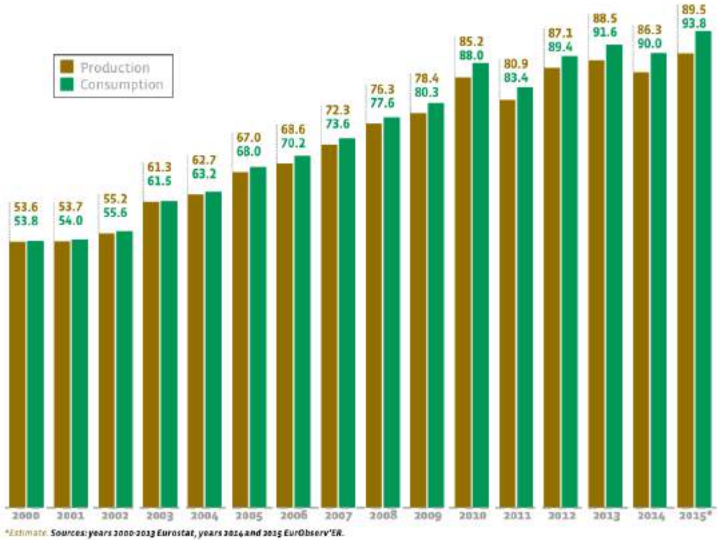

Figure 10.3. Solid biomass primary energy production and inland consumption growth figures for the EU since 2000 (in Mtoe) (Eurobserv'er: Solid biomass barometer 2016)

10.3 Sources of biomass for energy generation

10.3.1 Food crops

Food crops, such as sugarcane, corn, maize, soyabean, wheat, sugar beet and vegetable oils are used to produce biofuels: ethanol, biodiesel and petrol/diesel additives (see Figure 10.4) (Abbasi et al., 2010).

Food crops-to-energy programmes are under increasing scrutiny because they compete with the use of these crops as food, thereby pushing up food prices and threatening the existence of subsisting human beings. They also seriously degrade land and water bodies (Abbasi et al., 2010).

10.3.2 Hydrocarbon-rich plants

A large number of plants contain hydrocarbons in concentrations significant enough to become a potential source of a diesel like fuel. Even as great hope is pinned by some on these plants, the negative impact of their large-scale use is similar to that of food crops (Abbasi et al., 2010).

10.3.3 Waste

Waste includes agricultural residues (straw, vegetable/fruit peels and crop wastes), forestry waste, food waste and biomass components of municipal solid waste. Substantial energy can be produced from these wastes, because globally several billion tonnes of biomass is contained in them. But to actually extract the energy in a clean and costeffective manner is a major challenge yet to be met (Abbasi et al., 2010).

10.3.4 Weeds and wild growths

Invasive plants which outgrow their utility to humans are called weeds. Invasive plants elbow out most other species and have a destabilizing and degrading effect on the areas they colonize. If such plants can be utilized as energy source it would become economically feasible to periodically harvest and use them, thereby controlling their spread and reducing the harm they cause (Ganesh et al., 2009).

10.3.5 Fast-growing grasses and woody species

They include:

- Woody species such as willows, poplars and other hardwoods
- Herbaceous species such as switchgrass, big blustem, reed canarygrass and miscanthus

Of these, switchgrass has attracted particular attention due to its high biomass yield, broad geographic range, efficient nutrient utilization, low erosion potential, carbon sequestration capability, and reduced fossil fuel input requirements relative to annual crops (McLaughlin, Kszos, 2005).Care must be taken when selecting species for use as biofuel crops, because the characteristics which make some species ideal for this use, such as C4 photosynthesis, long canopy duration, lack of pests and diseases, and rapid spring growth, are the ones also associated with invasiveness (Raghu et al., 2006).

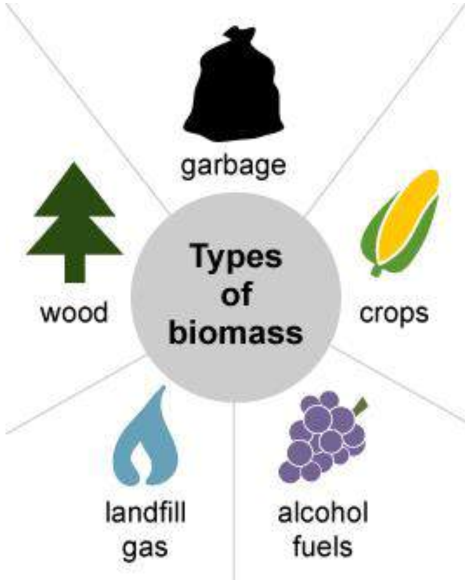

Figure 10.4. Sources of biomass for energy generation (US National Energy Education Project)

10.4 Converting biomass to other forms of energy

Burning is only one way to release the energy in biomass. Biomass can be converted to other useable forms of energy such as methane gas or transportation fuels such as ethanol and biodiesel.

Methane gas is a component of landfill gas or biogas that forms when garbage, agricultural waste, and human waste decompose in landfills or in special containers called digesters (EIA).

Crops such as corn and sugar cane are fermented to produce fuel ethanol for use in vehicles. Biodiesel, another transportation fuel, is produced from vegetable oils and animal fats (EIA).

Table10.1 enlists the sources of biomass and their uses for energy production.

Table 10.1. Examples of biomass and their uses for energy (www.eia.gov)

Source of biomass	Its use for energy production
Wood and wood processing wastes	Burned to heat buildings, to produce process heat in industry, and to generate electricity
Agricultural crops and waste materials	Burned as a fuel or converted to liquid biofuels
Food, yard, and wood waste in garbage	Burned to generate electricity in power plants or converted to biogas in landfills
Animal manure and human sewage	Converted to biogas, which can be burned as a fuel

10.5 Technical routes for the production of different types of energy from biomass

10.5.1 Thermochemical convertion of biomass

In thermochemical processing biomass is converted into a range of products by thermal decay and chemical reformation. It essentially involves heating biomass in the presence of differing concentrations of oxygen. When biomass is heated in total absence of oxygen, the pyrolysis process produces various organic liquids that can be manipulated or refined to make liquid fuels.

Alternatively, heating with low concentrations of oxygen leads to gasification and the production of hydrogen and organic gases which can also be converted into liquid fuels (Abbasi et al., 2010).

The start-up and plant maintenance costs of thermochemical processes are high because of the demands of high temperature processing. In order to operate efficiently, thermochemical processing must be done on a large scale which necessitates the transportation of biomass over long distances, resulting in an increase in cost. Also, thermochemical processes use up a lot of fossil fuels in the course of transportation of biomass and its heating (Abbasi et al., 2010).

10.5.2 Electricity from biomass-fired power plants

Direct combustion of biomass for power generation is a mature, commercially available technology that can be applied on a wide range of scales from a few MW to 100 MW or more and is the most common form of biomass power generation (see Figure 10.5). Around the globe, over 90% of the biomass that is used for energy purposes goes through the combustion route (IRENA, 2012).

There are two main components of a combustion–based biomass plant: the biomass-fired boiler that produces steam; and the steam turbine, which is then used to generate electricity. The two most common forms of boilers are stoker and fluidised bed. These can be fuelled entirely by biomass or can be co-fired with a combination of biomass and coal or other solid fuels. The steam produced in the boilers is injected into steam turbines. These convert the heat contained in the steam into mechanical power, which drives the generation of electricity (IRENA, 2012).

Figure 10.5. Sources of biomass for power generation (http://www.calbiomass.org/wp-content/uploads/2013/02/biomass-fuel-sources.jpg)

10.5.3 Cogeneration or 'combined heat and power (CHP)' generation

Cogeneration or CHP denotes the process which uses a single fuel to produce heat and electricity, thereby significantly increasing the overall efficiency. In normal electricity generation plants, up to 70% of heat in steam is rejected to the atmosphere. In cogeneration mode, this heat is used to meet process heating requirement (Abbasi et al., 2010). Combined heat and power operations often represent the most efficient use of biomass, utilizing around 80% of potential energy (see Figure 10.6) (EESI).

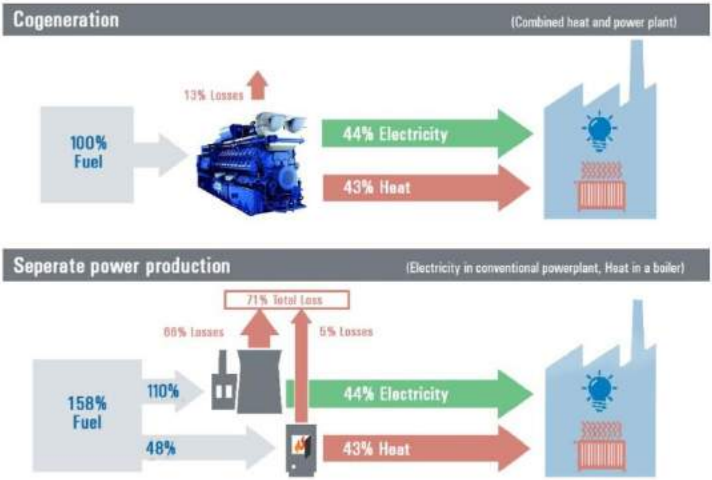

Figure 10.6. Cogeneration compared to seperate power production (Source: www.mwm.net)

Capacity of cogeneration projects can range from a few kilowatts to several megawatts of electricity generation along with simultaneous production of heat ranging from less than a hundred kWth (kilowatts thermal) to many MWth (megawatts thermal). CHP systems generally offer higher carbon savings than power only systems, but have less favourable economics mainly due to high initial capital costs (see Figure 10.7) (Abbasi et al., 2010).

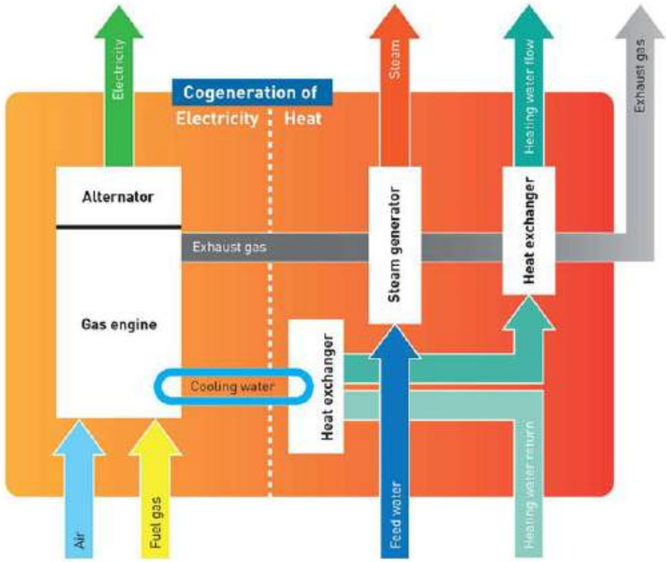

Figure 10.7. Principle of combined heat and power (CHP) plants with gas engines (Source: www.mwm.net)

10.5.4 Use of biomass gasifiers

Biomass gasifiers can be used to replace fossil-fuels in high fuelconsuming industries. Gasifier technologies offer the possibility of converting biomass into a producer gas, which can be burned in simple or combined-cycle gas turbines at higher efficiencies than the combustion of biomass to drive a steam turbine. Although gasification technologies are commercially available, more needs to be done in terms of R&D and demonstration to promote their widespread commercial use (IRENA, 2012).

There are three main types of gasification technology:

- Fixed bed gasifiers;
- Fluidised (circulating or bubbling) bed gasifiers; and
- Entrained flow gasifiers

10.6 Biochemical processing

10.6.1 Fermentation to ethanol

In the food crops the sugars are in the form of starch which has to be first converted to simpler sugars before fermentation to ethanol can be accomplished. As the fermentation is done in presence of water the resulting ethanol is in a dilute form. To be usable as a fuel, ethanol must be freed of water (Abbasi et al., 2010).

The big concern in connection with fermentation to ethanol is the conversion process which is far from clean. Some scientists even claim that the overall process is so polluting, and consumes so much energy, that in the ultimate analysis it generates more greenhouse gas emissions than the gasoline it replaces as a transportation fuel.

10.6.2 Production of ethanol from lignocellulosic crop

With growing opposition to the diversion of food crops for biofuel production, and growing acceptance of the fact, that it is not as clean and green process as has been projected in the past, focus is shifting towards lignocellulosic biomass. Whereas the starch-rich seeds of corn or maize constitute but a small fraction of the biomass of the overall plant, all other parts of plants are full of lignocellulose. Hence for every acre of land committed to biomass for energy, much greater quantities of lignocellulosic biomass can be produced than a food crop (Abbasi et al., 2010).

10.6.3 Anaerobic digestion

It has been used with increasing success in processing animal manure and wastewaters (Ramasamy et al., 2004), but has been besieged with operational problems and low efficiency when used to process phytomass (Ganesh et al., 2009).

10.6.4 Esterification to biodiesel

The main challenge is to grow oil-rich plants in sufficiently large quantities per acre of land to maximize oil yield with minimum of environmental costs (Abbasi et al., 2010).

10.6.5 Emerging technologies

New technologies for producing biofuels from biomass are rapidly emerging, including the development of engineered yeast for increased ethanol yields (Alper et al., 2006), utilization of new microorganisms for ethanol production (Seo et al., 2005), pretreatments for cellulosic digestion (Mosier et al., 2005), fuel cells for converting sugars directly to electricity (Chaudhury, Lovley, 2003) and catalysts for more efficient conversion of biomass to syngas (Salge et al., 2006).

10.7 Environmental impacts of biomass energy

10.7.1 Production of biomass

Biomass energy may be carbon neutral but it is not nutrient neutral

Central to the advocacy of biomass energy is the argument that it is carbon neutral; it releases only that carbon back to the atmosphere which was earlier plucked out form there by photosynthesis. The argument is valid, even if we consider the fact that at least a part of the carbon fixed by the biomass in recent years might have been a fossil fuel origin (Abbasi et al., 2010).

But biomass is not merely a lump of carbon, it contains nitrogen and several other essential nutrients. Any effort to intensively cultivate biomass has implications other than carbon capture (Miller et al., 2007)

Agricultural activities generate more than 75% of emitted reactive nitrogen compounds (Smil, 1999). Global atmospheric CO_2 concentrations have increased by about one-third since 1750; during the same period, a 15% increase in atmospheric N_2O concentrations has occurred, but each molecule of N_2O has 300 times greater global warming potential than a molecule of CO_2 (Fixen, West, 2002). Moreover, anthropogenic disruptions in the nitrogen cycle have led to an estimated 1100% increase in the flux of nonreactive atmospheric nitrogen to reactive nitrogen compounds (Gitay, Suarez, 2002).

Once converted to a reactive state, nitrogen persists in the environment, passing through the forms of $NH_3 \rightarrow N_2O \rightarrow NO_x \rightarrow NO_3$; resulting in impacts such as the production of ground-level ozone, acidification, eutrophication, hypoxia, stratospheric ozone depletion, and climate change (Galloway et al., 2003). Of these impacts, eutrophication of surface water bodies and contamination of underground aquifers are among the most widespread of the environmental impacts of agriculture. Phosphorous cycles are also effected leading to eutrophication (Abbasi et al., 2010).

It is not possible to sustain the intensive and repetitive production of biomass per unit land area envisaged in the biomass-based energy production programmes on the basis of the native nitrogen stocks in the soil as they are insufficient to supply enough nutrients to sustain non-nitrogen-fixing crops, such as corn. The natural levels of nitrogen have to be augmented with additional nutrients, generally in the form of synthetic fertilizer, but soil organic matter, soil biota, water-holding capacity of the soil, and numerous microneutrients can not be replaced with fertilizers (Abbasi et al., 2010).

10.7.2 Land and water resources

Implementing a substantial biomass energy production program requires large amounts of water resources and land. In some regions, groundwater is being pumped 10 times faster than the natural recharge potential of the aquifers. Another problem is the water pollution via the pesticides and fertilizers that are inevitably needed in sustaining any intensive cultivation (Pimentel et al., 1992).

The land used for increased biomass production for energy competes with crops, forests, and urbanization (Chari, Abbasi, 2005). The removal of biomass from land and water for energy production programme increases soil and water degradation, flooding, and removal of nutrients. It also affects wildlife and the natural biota (Abbasi et al., 2010).

10.7.3 Soil erosion and water run-off

Biomass energy production projects are likely to exacerbate soil erosion problems. Soil erosion contributes significantly in hastening water run-off, thus, retarding groundwater recharge; the nutrient-rich run-off can harm the quality of receiving rivers, lakes or estuaries by causing eutrophication (Abbasi, Chari, 2008).

10.7.4 Nutrient removal and losses

Significant nutrient loss is incurred by the harvesting of crop residues for biomass energy.

10.7.5 Loss of natural biota, habitats and wildlife

Conversion of natural ecosystems into energy-crop plantations will change both the habitat and food sources of wildlife and other biota (Abbasi, Chari, 2008). Alteration of forests and wetlands will reduce many preferred habitats and mating areas of some mammals, birds, and other biota. Monoculture plantations of fast-growing trees reduce the diversity of vegetation and the value of the areas as habitats for many wildlife species. These monocultures are less stable than climate forests and require increased energy inputs in the form of pesticides and fertilizers to maintain productivity. Trees in profitable plantations are 2–3 times as dense as those of natural forests (Rowe at al., 2009).

10.8 Conversion to utilizable energy

Production of biomass is only one dimension of the biomass-based energy systems; its conversion to utilizable energy is another and equally important dimension (Abbasi et al., 2010).

Biomass utilization is a source of not only GHG emissions but several highly toxic air pollutants (Lewtas, 2007).

10.8.1 Environmental impact of thermal processes

The main environmental problems are:

(a) air pollution → emissions of particulates, carbon oxides, sulphur oxides, nitrogen oxides;

(b) organic emissions → dioxin, hydrocarbons, toxic irritants and carcinogenic compounds;

(c) generation of solid wastes → bottom ash, flyash sometimes containing toxic substances with accompanying pollution problems;

(d) water pollution → biological oxygen demand, chemical oxygen demand, suspended solids, trace metals;

(e) pressure on land and water resources;

(f) household hazards → accidental fires;

(g) occupational hazards → prolonged exposure to toxic and corrosive chemicals.

10.8.2 Burning wood

Using wood, wood pellets, and charcoal for heating and cooking can replace fossil fuels and may result in lower CO_2 emissions overall. At the same time wood smoke contains pollutants like carbon monoxide and particulate matter. Modern wood-burning stoves, pellet stoves, and fireplace inserts can reduce the amount of particulates from burning wood. Wood and charcoal are major cooking and heating fuels in poor countries, but if people harvest the wood faster than trees can grow, it causes deforestation (EIA).

10.8.3 Use of Biomass for Power and Heat

The use of wood for electricity generation and heat has grown rapidly in recent years, but its real impact on the climate and on forests is controversial. Just like the debate around transport biofuels a few years ago, this has become a very controversial subject with very few areas of consensus (Chatam House).

Most current support policies for biomass for power and heat are based on the incorrect assumption that its use is immediately and completely carbon-neutral. This assumption underpins many public policies, with the result that biomass use is expanding, mostly to the detriment of attempts to limit climate change. In reality biomass emits more carbon per unit of energy than most fossil fuels. Only residues that would otherwise have been burnt as waste or would have been left in the forest and decayed rapidly can be considered to be carbon-neutral over the short to medium term (Chatam House).

One reason for the perception of biomass as carbon-neutral is the fact that, under international greenhouse gas accounting rules, its associated emissions are recorded in the land use rather than the energy sector. However, the different ways in which land use emissions are accounted for means that a proportion of the emissions from biomass may never be accounted for (Chatam House).

10.8.4 Burning municipal solid waste or wood waste

Burning municipal solid waste to produce energy in waste-to-energy plants means that less waste is buried in landfills. On the other hand, burning garbage produces air pollution and releases the chemicals and substances in the waste into the air. Some of these chemicals can be hazardous to people and the environment if they are not properly controlled (EIA).

Scrubbers clean emissions from waste-to-energy facilities by spraying a liquid into the combustion gases to neutralize the acids present in the stream of emissions. Fabric filters and electrostatic precipitators also remove particles from the combustion gases. A waste-to-energy furnace burns at high temperatures (1000-1100 °C), which breaks down the chemicals in municipal solid waste into simpler, less harmful compounds (EIA).

10.8.5 Disposing ash from waste-to-energy plants

Ash can contain high concentrations of various metals that were present in the original waste. Batteries are the largest source of lead and cadmium in municipal waste. Textile dyes, printing inks, and ceramics may also contain lead and cadmium. Florescent light bulbs contain small amounts of mercury. Separating waste before burning can solve part of the problem (EIA).

10.8.6 Collecting landfill gas or biogas

Biogas forms as a result of biological processes in sewage treatment plants, waste landfills, and livestock manure management systems. Biogas is composed mainly of methane and CO_2. Many facilities burn the methane for heat or to generate electricity and it may replace electricity generation from fossil fuels and can result in a net reduction in CO_2 emissions but burning methane also produces CO_2 and because methane is a stronger greenhouse gas than CO_2, the overall greenhouse effect is lower.

10.8.7. Impact of fermentation processes; liquid biofuels: ethanol and biodiesel

Biofuels may be carbon-neutral because the plants that are used to make biofuels (such as corn and sugarcane for ethanol and soy beans and palm oil trees for biodiesel) absorb CO_2 as they grow and may offset the CO_2 emissions when biofuels are produced and burned EIA).

Nevertheless, growing plants for biofuels is controversial, because the land, fertilizers, and energy for growing biofuel crops could be used to grow food crops instead. In some parts of the world, large areas of natural vegetation and forests have been cut down to grow sugar cane for ethanol and soybeans and palm oil trees for biodiesel (EIA).

These activities contribute a lot more to global warming, over a short term as well as a long term, than the savings achieved by replacing some portions of gasoline by ethanol in transportation fuel (Searchinger et al., 2008).

There are alternative sources of biomass that do not compete with food crops and that use less fertilizer and pesticides than corn and sugar cane. Ethanol can also be made from waste paper, and biodiesel can be made from waste grease and oils and even algae (EIA). There is increasing advocacy for biofuel production from lignocelluloses-based energy crops such as switchgrass, willows and poplars, especially using agriculturally marginal land (Schmer et al., 2008).

Ethanol and gasoline-ethanol blends burn cleaner and have higher octane ratings than pure gasoline, but they have higher evaporative emissions from fuel tanks and dispensing equipment. These evaporative emissions contribute to the formation of harmful, ground-level ozone and smog. Gasoline requires extra processing to reduce evaporative emissions before it is blended with ethanol. Biodiesel combustion produces fewer sulfur oxides, less particulate matter, less carbon monoxide, and fewer unburned and other hydrocarbons, but it does produce more nitrogen oxide than petroleum diesel (EIA).

Eventhough life cycle assessment studies show biofuels favourable in net energy balance (NEB) in comparison to the fossil fuels they replace (Schmer et al., 2008), biofuels look less and less attractive if viewed in the total context of energy balance, GHG emissions, environmental impact, and humanism (Abbasi et al., 2008).

References

Abbasi, Tasneem, Abbasi, SA: Biomass energy and the environmental impacts associated with its production and utilization; Renewable and Sustainable Energy Reviews, Volume 14, Issue 3, April 2010, Pages 919-937

Abbasi SA, Chari KB. Environmental management of urban lakes. New Delhi: Discovery Publishing House; 2008.

Alper H, Moxley J, Nevoigt E, Fink GR, Stephanopoulos G. Engineering yeast transcription machinery for improved ethanol tolerance and production. Science 2006;314:1565–8.

Chari KB, Abbasi SA. A Study on the aquatic and amphibious weeds of Oussudu Lake. Hydrology Journal 2005;28(September–December):89–98F.

Chatham House (International Affairs Think Tank) (https://www.chathamhouse.org/about/structure/eer-department/environmental-impact-use-biomass-power-and-heat-project)

Chaudhuri SK, Lovley DR. Electricity generation by direct oxidation of glucose in mediatorless microbial fuel cells. Natural Biotechnology 2003;21:1229–32.

EESI: (http://www.eesi.org/topics/bioenergy-biofuels-biomass/description)

EIA (U.S. Energy Information Administration) www.eia.gov

Eurobserv'er: Biofuels barometer 2017

Eurobserv'er: Solid biomass barometer 2016

Fixen PE. West FB nitrogen fertilizers, meeting contemporary challenges. AMBIO 2002;31:169–76.

Galloway JN, Aber JD, Erisman JW, Seitzinger SP, Howarth RW. The nitrogen cascade. BioScience 2003;53L:41–356.

Ganesh PS, Gajalakshmi S, Abbasi SA. Vermicomposting of the leaf litter of acacia (Acacia auriculiformis): Possible roles of reactor geometry, polyphenols, and lignin. Bioresource Technology 2009;100:1819–27.

Gitay HA, Suarez T. In: Watson, Dokken DJ, editor. Climate Change and Biodiversity. IPCC Technical Paper V. Geneva: Intergovernmental Panel on Climate Change; 2002.

Goldemberg J, Johansson TB. World energy assessment overview: update. New York: United Nations Development Programme; 2004.

IRENA: Renewable Energy Technologies: Cost Analysis Series – Biomass for Power Generation, 2012

Lewtas J. Air pollution combustion emissions: characterization of causative agents and mechanisms associated with cancer, reproductive, and cardiovascular effects. Mutation Research—Reviews in Mutation Research 2007;636:95–133.

McLaughlin SB, Kszos LA. Development of switchgrass (Panicum virgatum) as a bioenergy feedstock in the United States. Biomass and Bioenergy 2005; 28:515–35.

Miller SA, Landis AE, Thesis TL. Environmental trade-offs of biobased production. Environmental Science & Technology 2007;(August):5176–82.

Mosier N, Wyman C, Dale B, Elander R, Lee YY, Holtzapple M, Ladisch M. Features of promising technologies for pretreatment of lignocellulosic biomass. Bioresource Technology 2005;96:673–86.

Pimentel D. Competition for land: development, food, and fuel. In: Kaliasha MA, Zcker A, Ballew KJ, editors. Technologies for a Greenhouse-constrained Society, Lewis, Boca Raton, FL; 1992. p. 325–48.

Raghu S, Anderson RC, Daehler CC, Davis AS, Wiedenmann RN, Simberloff D, et al. Adding biofuels to the invasive species fire? Science 2006;313:1742.

Ramasamy EV, Gajalakshmi S, Sanjeevi R, Jithesh MN, Abbasi SA. Feasibility studies on the treatment of dairy wastewaters with upflow anaerobic sludge blanket reactors. Bioresource Technology 2004;93:209–12.

Rowe L, Street R, Taylor NR. GIdetifying potential environmental impacts of large-scale development of dedicated bioenergy crops in the UK. Renewable and Sustainable Energy Reviews 2009;13:271–90.

Salge JR, Dreyer BJ, Dauenhauer PJ, Schmidt LD. Renewable hydrogen from nonvolative fuels by reactive flash volatilization. Science 2006;314:801–5.

Scheer, Hermann: Handbook of Renewable Energies in the European Union I-II; Frankfurt am Main, Germany, 2002

Schmer MR, Vogel KP, Mitchell RB, Perrin RK. Net energy of cellulosic ethanol from switchgrass. USA: Proceedings of the National Academy of Sciences 2008.

Searchinger T, Heimlich R, Houghton RA, dong F, Elobeid A, Fabiosa J, et al. Use of croplands for biofuels increases greenhouse gases through emissions from land-use change 10.1126/Science.1151861. Science 2008;319:1238–40.

Seo JS, Chong H, Park HS, Yoon KO, Jung C, Kim JJ. The genome sequence of the ethanologenic bacterium Zymomonas mobilis ZM4. Nature Biotechnology 2005;23:63–8.

Smil V. Nitrogen in crop production: an account of global flows. Global Biogeochemical Cycles 1999;13:647–62.

US National Energy Education Project

World Bioenergy Association: Global Bioenergy Statistics 2014

World Energy Council: World Energy Resources – Bioenergy 2016.