1

Energy and Environment Perspectives

1.1 Introduction

Humanity has been struggling with many global issues such as energy, water, food, education, pandemic and diseases, terrorism and wars, population increase, immigration and refugees, poverty, and environment as illustrated in Figure 1.1 that makes the world cry. This is primarily because of the anthropogenic activities where fossil fuels in global energy portfolio have played a critical, but damaging role. There have been various researchers and institutions making various lists of problems or ranking the global challenges, and they have more or less ended up with the same or similar items, ranging from energy to water and from food to environment. Almost all countries have been affected by one or more, or all of these items as presented in Figure 1.1. Among these, energy is of course listed one of the top-ranked challenges as it is essential to drive the sectors, economies, and hence societies for their activities. During the past a few years, it has been crystal clear to all of us that the COVID-19 pandemic has changed many tangible and intangible things in our daily life, personal relations, institutional arrangements, country affairs, energy matters, business, trade, politics, economy, education, social life, etc. Although each item has a unique impact on people's lives, some of them, for example, energy, are affecting the rest of the items significantly. Energy is recognized as a significant necessity which is considered responsible for many issues in particular related to ecosystem, air, water, and food. For instance, traditional energy systems which use fossil fuels cause air pollution and water pollution issues. The emissions, in particular greenhouse gas (GHG) emissions, cause major environmental challenges, such as global warming (or greenhouse effect) and stratospheric ozone depletion. For example, due to the global warming we face water scarcity in many parts of the world causing crises in many sectors, including agricultural sector.

Furthermore, each item given in Figure 1.1 is, no matter, of great importance. However, one may extract four out of them, namely clean energy, clean air, clean water, and clean food, that affected the past, are affecting the present, and will probably affect the future of humanity. Clean energy plays a key role among these four key humanity-needs as the nature and cleanliness of energy may badly influence the other three, namely air, water, and food. Here, clean energy primarily refers to renewable energy where we use renewable energy sources, such as solar, wind, geothermal, hydro, marine and biomass to generate clean outputs (for example, electricity, heat, and cooling) for daily sectoral applications. Energy is essentially needed for almost every operation or application or process in our daily life. Therefore, clean energy has a crucial role in providing clean air, clean food and clean water which will result in a more sustainable community.

Since the food chain from harvesting to the shelf is so diverse and there are many processes involved which are energy intensive and fuel consuming, they require huge amounts of energy and fuels,

Introduction to Energy Systems, First Edition. Ibrahim Dincer and Dogan Erdemir.

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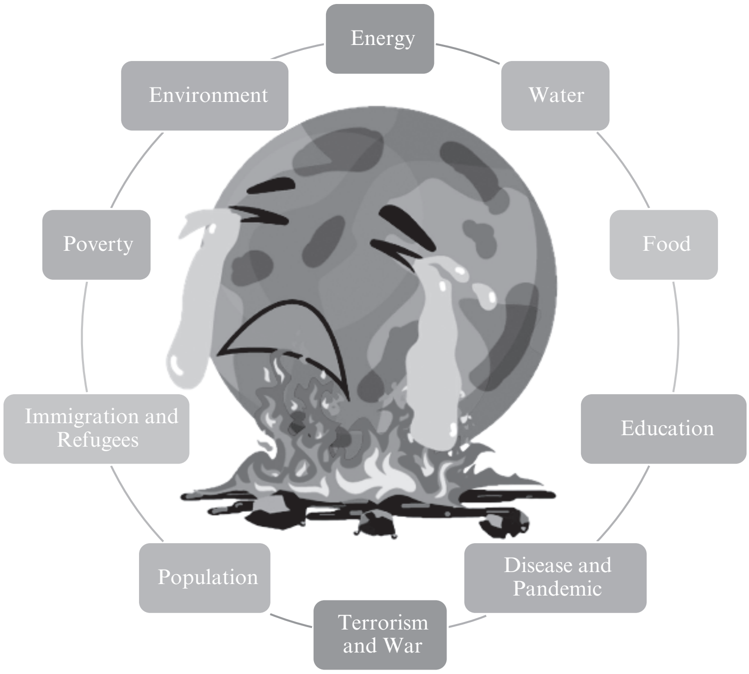


Figure 1.1 Global challenges affecting the people's past, present and future.

accounting for over 30% of the world's total energy consumption. Of course, having more and more processed foods coming to our tables, due to the advanced preservation and processing technologies as well as rising population, will even increase this much more. For example, ammonia is one of the most essential inputs for agriculture since it is used as fertilizer, or agricultural machinery consumes a voluminous fuel for tillage. Also, water is the most significant input for agriculture and aquaculture. Pumps used in watering or oxygen generators used in aquaculture consume a considerably high amount of energy. On the other hand, the transportation of the agricultural products is an indispensable part of the food-supply chain. Clean transportation options will help achieve clean food and clean air targets. Moreover, electricity is consumed to preserve the food in the refrigerator. Consequently, energy, food, environment and water are really connected very much to each other. So, we need to find newly developed and innovative options to operate all these steps in a sustainable manner.

Although the Earth is called as the water planet, almost 99% of the water resources on the Earth are not usable by people. It is widely known that about 1% of the water sources is fresh water in a drinkable form which is largely found in lakes, rivers, and underground sources. In order to obtain fresh water from the remaining 99% of the unusable forms of water, water should be cleaned and hence desalinated accordingly, which again requires a significant amount of energy for operation. So, clean energy will really be the key to clean water, too. Finally, this shows us that it may not take too much time to be faced with the water crisis.

Energy itself is, no doubt, an essential need for people, and the amount of energy consumption has been ever-increasing in the world due to the increasing population, the rising living standards, and the comfort level requirements in almost all sectors. Today, most of the energy demands are met by fossil fuel-based systems, and the consumption of fossil fuels is also increasing day by day. Fossil fuels can be assumed to be one of the major contributors to environmental problems. The increasing energy consumption and environmental problems have compelled people to use energy more efficiently, especially in existing energy systems and to benefit from clean energy sources (renewables and nuclear).

We begin this chapter with the importance of energy and how to solve energy issues effectively. Next, the smart solutions to solve these issues are discussed. The role of engineering is essentially introduced and discussed for solving energy-based problems. Then, the introductory information on environmental issues, industrial ecology, and life-cycle assessment is presented. Finally, the importance of energy labeling is discussed along with some examples.

1.2 Importance of Energy

It is a common fact that life is impossible without energy which is an essential driver for anything and everything. Energy is vital for our daily life and sectoral activities. Some examples may be introduced as follows:

- In our home for lighting, appliances, televisions, computers, air conditioners, etc.
- In factories to power the manufacturing processes; and
- In transportation for cars, trucks, ships, airplanes to transport people and goods.

The energy demand in the world has been ever-increasing due to the growing population and enhanced living standards. Figure 1.2 demonstrates the global changes in the world energy consumption (in Figure 1.2a), world gross domestic product (Figure 1.2b), and world population with respect to years (Figure 1.2c). The world's population is also projected to be around 10 billion by the year 2050, as seen in Figure 1.2a. Most of the population will eventually require food, energy, shelter, water, etc. more than what people have today. The increase in the population definitely results in a substantial amount energy consumption. As seen from Figure 1.2a, by 2050, it is

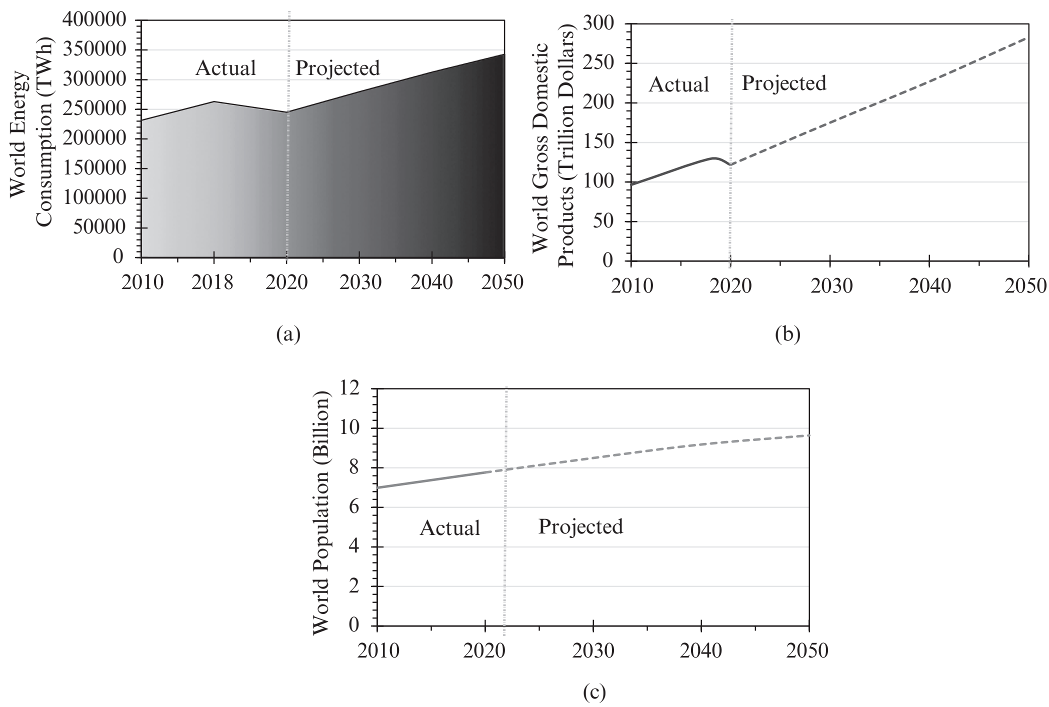


Figure 1.2 The projections of (a) the world energy consumption, (b) gross domestic product, and (c) population (data from [1]).

expected to drastically increase in the global energy use approximately by 50%. The biggest contribution in this increase is done by non-OECD economic growth and population. Also, the increasing population will require more domestic products. Figure 1.2b shows the historical and projected data for world gross domestic product changes. It is expected to increase more than double. These numbers clearly show that urgent action is really required for a sustainable future, especially in energy production and consumption.

1.3 Energy Issues

All sectors have relied on energy as a constant source of power. Over time, energy has become more important, especially after the industrial revolution. Many economic domains and areas have been governed by it, such as relationships, business deals, wars, terrorist activities, etc. At present, it dominates more than ever and will certainly dominate far more in the future. The present civilization has a fundamental responsibility to deal fairly and diligently with this issue.

The increasing world population and the rising living and working standards in all sectors have been the reasons behind the worldwide ever-rising energy consumption. Figure 1.3 illustrates the total amount of energy consumption around the world by source from 1965 to 2020. As mentioned previously, the global energy consumption has increased significantly every year. Figure 1.3 also highlights that fossil fuels cover nearly 65% of the global energy demand. Additionally, while the decrease in energy consumption in 1972–1975, 1979–1983, and 2008 have occurred due to economic recession, it has occurred due to the COVID-19 pandemic occurred in 2020. From 1965 to 2020, energy consumption increased approximately four times.

Fossil-based fuels essentially meet almost two-third of the global energy demand. They also have some risks due to their limited and nonhomogeneous reserves, environmental impacts, and energy security concerns. These risk factors have forced people toward alternative energy sources and systems such as renewable energy sources. Traditional energy systems dramatically pollute the environment, so, today, we are talking about the net zero emissions target, clean energy technologies, etc. Also, with the oil crisis that emerged in October 1973, the interest in alternative energy sources has

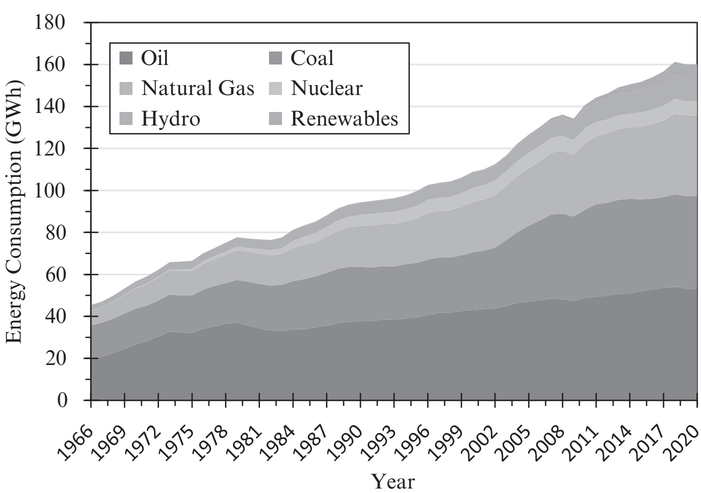


Figure 1.3 Total energy consumption of the world by sources (data from [2]).

increased significantly. Especially, solar domestic hot water systems and other solar space heating systems have become prevalent after the oil crisis. The use of renewable energy sources has increased significantly over the past decade. Despite the magnificent advantages of renewables in terms of energy security and environmental impact, the biggest disadvantage in their use is that they are mostly non-continuous energy sources, such as solar and wind, due to their fluctuating nature [3].

Another issue with energy is the difference between the energy supply and demand profiles. The energy demand profiles vary with respect to the sectors (residential, industrial, commercial, etc.) and time frame (daily, weekly, seasonal, yearly etc.). For instance, when the weekly energy demand profiles of the industrial and commercial sectors are considered, their energy demands tend to decrease on the weekends due to lowering activities in these sectors. In the residential buildings, against to the commercial and industrial sectors, the energy demands are higher on the weekends due to increasing time spent in residential units and indoor activities. When the yearly energy demand profile is taken into consideration for all sectors, it is quite higher during the summer due to the intensive air conditioner (AC) usage. That is why the highest electricity consumption rates are observed in the summer months.

In addition to these two issues, the peak loads are another issue faced in the energy field. Fluctuating trend in energy demand means peak energy loads, which requires a substantially higher amount energy according the off-peak and average loads. Peak loads are also seen in the short time depending on the time frame considered. For example, the highest cooling loads which are almost 50% higher than the average load, are seen 2–4 hours in a day. On a yearly basis, the highest electricity consumption is seen in the few hottest weeks in summer in many countries. In order meet the peak load, high-capacity devices should be included in the buildings for micro scale (buildings, factories, etc.). For macro scale such as communities, regions, countries, extra power plants or energy imports are required to meet the peak energy demands. Extra power plants and energy imports bring with it a high cost for energy supply. The different tariff structures, called triple tariff or multi tariff, are used to cover a part of this high-cost energy. Also, the time-of-use tariffs aim to promote to reduce energy consumption for savings during peak periods and to shift the peak demand from peak hours to off-peak hours. In order to avert those issues in the energy use and reduce the environmental impact due to energy consumption, we need to find smart solutions which will be presented forthcoming sections.

1.4 Environmental Issues

Energy supply and demand are related not only to problems such as global warming but also to such environmental concerns as air pollution, ozone depletion, forest destruction, and emissions of radioactive substances. All of them are called environmental impact categories. All environmental impact categories must be taken into consideration if human society is to develop in the future while maintaining a healthy and clean environment. Much evidence suggests that the future will be negatively impacted if people and societies continue to degrade the environment. Figure 1.4 shows the energy related CO_2 emissions in the world. CO_2 emissions have exponentially increased, and it is therefore expected that it will continue increasing with the increasing energy consumption. If current policy and technology trends continue, global energy consumption and energy-related carbon dioxide emissions will increase through 2050 as a result of population and economic growth. Renewables will be the primary sources for new electricity generation, but natural gas, coal, and increasingly batteries will be used to help meet load and support grid reliability. Oil and natural gas production are still expected to continue in a growing manner, mainly to support increasing energy consumption in developing countries, including Asian economies.

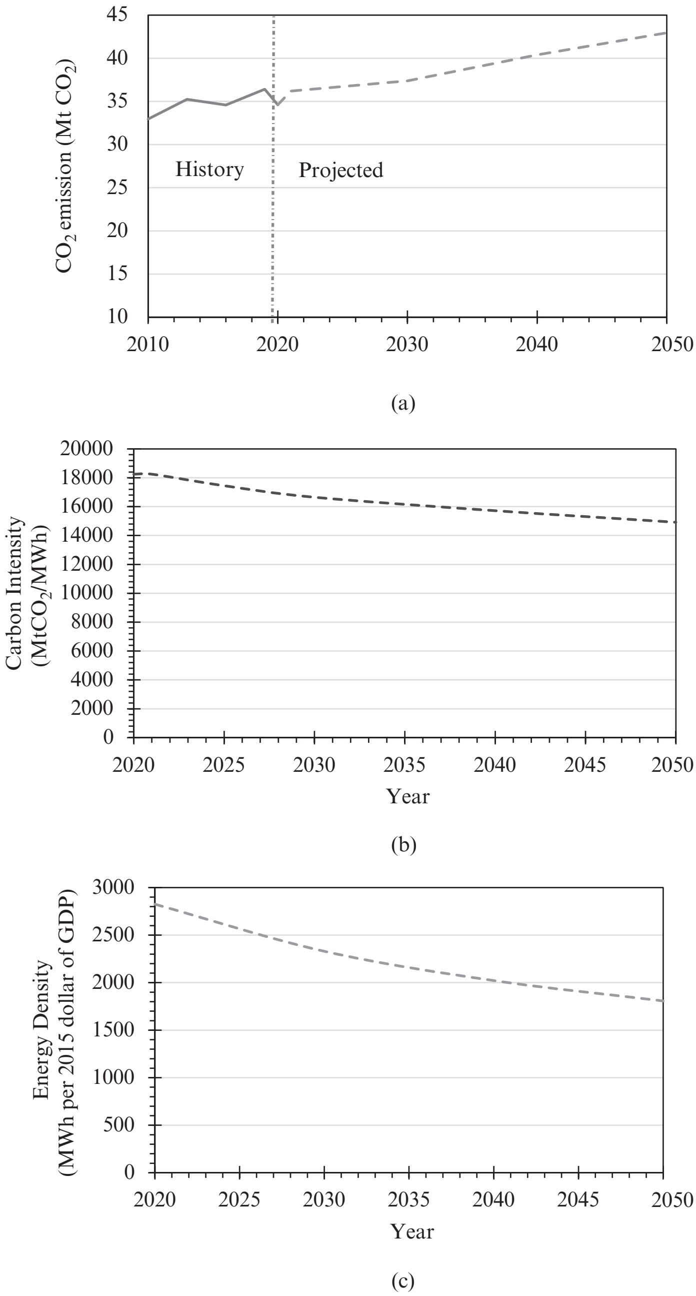


Figure 1.4 Energy related (a) carbon dioxide (CO_2) emissions, (b) carbon intensity and (c) energy intensity (data from [1]).

There is an intimate connection between energy, the environment, and sustainable development. A society seeking sustainable development ideally must utilize only energy resources that cause no environmental impact (e.g., which release no emissions or only harmless emissions to the environment). However, since all energy resources lead to some environmental impact, it is reasonable to suggest that some (but not all) of the concerns regarding the limitations imposed on sustainable development by environmental emissions and their negative impacts can be overcome through increased energy efficiency. A strong correlation clearly exists between energy efficiency and environmental impact since, for the same services or products, less resource utilization and hence pollution are normally associated with higher efficiency processes.

Achieving solutions to the environmental problems that we face today requires long-term planning and actions, particularly if we are to approach sustainable development. In this regard, renewable energy resources appear to represent one of the most advantageous solutions. Hence, a strong connection is often reported between renewable energy and sustainable development. Environmental considerations have been given increasing attention in recent decades by energy industries and the public. The concept that consumers share responsibility for pollution and its impact and cost has been increasingly accepted. In some jurisdictions, the prices of many energy resources have increased over the last 20 years, in part to account for environmental remediation costs. It is really necessary to look at some major environmental issues which are listed below:

- Acid rain: It results when sulfur dioxide and nitrogen oxides are emitted into the atmosphere and transported by wind and air currents. The combustion of the fossil fuels is the main contributor of acid rain.
- Stratospheric ozone depletion: it is used for defining the thickness of the ozone later in the stratosphere.
- Global warming and climate change: Global warming and climate change occur due to greenhouse emissions created by human activities.
- Hazardous air pollutants: include carbon monoxide, lead, nitrogen oxide, ozone, sulfur dioxide etc., which are mainly formed by burning fossil fuels.
- Poor ambient air quality: Air quality is defined over oxygen, carbon monoxide, carbon dioxide, and nitrogen oxide and hazardous air pollutants in the air. Combustion of fossil fuels and husbandry results in a poor ambient air quality.
- Water and maritime pollution: occur when the mixture of chemical and trash are disposed to the lakes, rivers, sea, and oceans. This pollution causes damages in the environment and living organisms in the water. It breaks down the balance of the world.
- Land use and siting impact: it is related to the economic and cultural activities which happen at a location. It can cause impervious surfaces, point source discharges, and development patterns. It affects quality of water and watersheds, loss of native habitats and spread of invasive species.
- Radiation and radioactivity: Radiation is the particles or energy released during radioactive decay. Radioactivity is the natural process by which some atoms spontaneously disintegrate, emitting both particles and energy as they transform into different, more stable atoms. Everyone is exposed to radiation on a daily basis, primarily from naturally occurring cosmic rays, radioactive elements in the soil, and radioactive elements are incorporated in the body. Man-made sources of radiation, such as medical X-rays or fallout from historical nuclear weapons testing also contribute, but to a lesser extent. About 80% of background radiation originates from naturally occurring sources, with the remaining 20% resulting from man-made sources.
- Solid wastes: Solid wastes are produced with almost every activity done by people. Their collection for disposal requires energy. Diverting waste by recycling and composting can help reduce the impact of solid waste on the environment.
- Environmental accidents: Anthropogenic environmental disasters such as nuclear accidents, oil leakages, chemical waste dumps, forest fires, and many more can be included in major environmental accidents. Better engineering, engineering materials, and people's education can help to reduce the number of such accidents.

- Thermal pollution: It is the degradation of water quality by any process that changes ambient water temperature. It occurs when cooling of the thermal and nuclear power plants are done by water sources such as lake, sea, and river. Thermal pollution, unlike chemical pollution, results in a change in the physical properties of water.

Various potential solutions to the current environmental problems associated with harmful pollutant emissions have recently evolved, including:

- use of renewable energy technologies,
- use of advanced nuclear energy technologies,
- integration of energy storage systems into existing systems for better management practices,
- efficient energy use and energy conservation,
- development of district energy systems, including heating and cooling,
- use of clean energy sources and fuels for transportation vehicles,
- energy-source switching from fossil fuels to more environmentally benign-energy forms,
- use of clean coal technologies,
- optimum monitoring and evaluation of energy indicators,
- policy and strategy development and deployment,
- recycling and waste management practices,
- development of waste to energy (i.e., power) options,
- process improvement and sectoral rehabilitation studies,
- acceleration of forestation,
- implementation of carbon and/or fuel taxes,
- greener material substitutions,
- promoting public transportation,
- changing lifestyles,
- increasing public awareness of energy-related and environmental problems,
- increased ethical responsibilities related to resources and their utilization,
- environmentally-focused education and training.

1.5 Smart Solutions

As mentioned previously, energy is recognized as an essential part of our life for everything, but causes the serious problems for environment, economy, development and sustainability if it is not clean enough. Here, the key question will be "How to meet future energy needs in a sustainable manner?" In order to meet the future's energy demand in a sustainable way, we really need the smart and reasonable solution covering clean energy sources, energy storage technologies, multi-objective optimizations, and real-time controlling. In order to reach smart solutions in the energy field, first, we need to identify our targets. Figure 1.5 demonstrates the key targets for the smart solutions to reach a sustainable future.

It is widely experienced that things are getting smarter and better day by day. That's why we have smart materials, smart devices, smart technologies, smart grid, etc. Also, we really need smart energy solutions. The smart energy portfolio is apparently expected to provide nine solution areas as illustrated in Figure 1.6. In order to reach the smart solutions, the following technologies, methods and strategies should be included into the systems, processes and services accordingly:

- Renewable energy technologies: Renewables are one of the significant solutions to generate energy in a clean way for local and global activities. Therefore, they should be the first option in order to generate power in any location where we have any renewable source available.

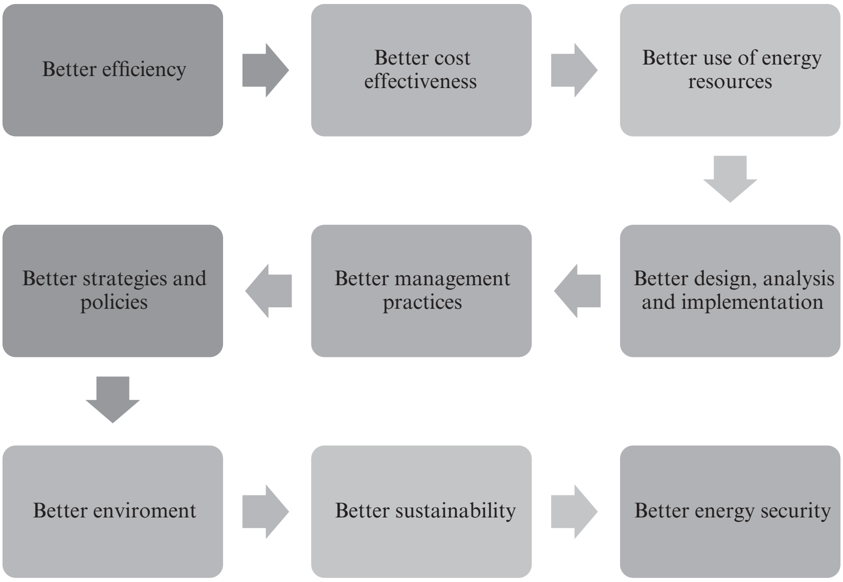


Figure 1.5 The targets to reach the smart solutions.

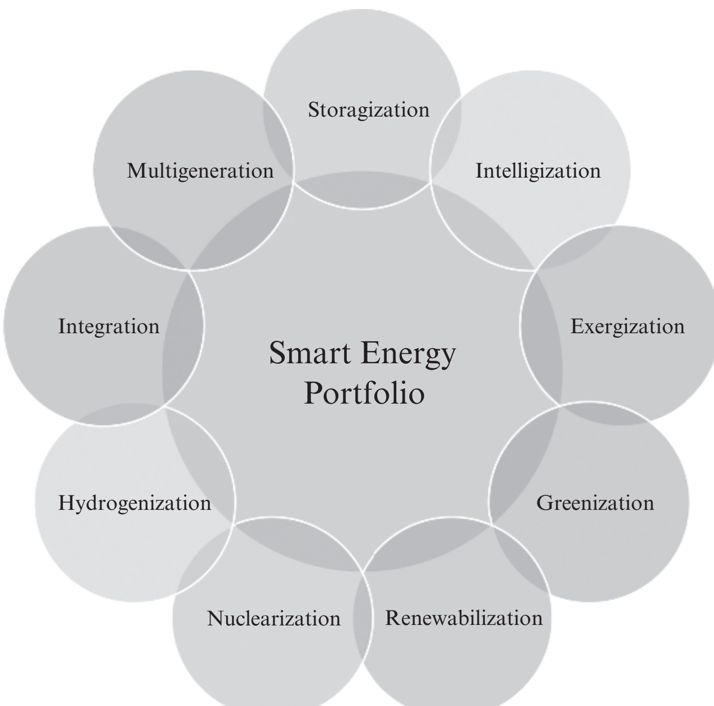


Figure 1.6 Nine branches of smart energy portfolio (modified from [4]).

- Clean fuel technologies (hydrogen, ammonia, etc.): Fuels are critical especially for the mobility. The systems should be developed, where we use carbon free fuels, such hydrogen and ammonia, instead of fossil fuels.
- Efficient energy use: Energy efficiency is called as the one best "energy source" to reduce the energy consumption and emissions since many systems are still using inefficient energy

conversion systems. Using energetically efficient systems, devices, processes and services will help to reduce energy consumption and emission depending on them.

- Cleaner technologies for fossil fuels: Fossil fuels are still expected to continue covering the main part of our daily life activities for some years, which may range from one decade to two decades. In order to reduce their environmental impacts, cleaner techniques for fossil fuels are badly needed to reduce their carbon footprints in the near future.
- System integration and multigeneration: Instead of using a conventional energy system which consists of a source, a system, and service, we need to obtain more useful outputs from a source in order to increase the efficiency. Therefore, multigeneration systems play a key role for sustainability.
- Energy storage technologies: Energy storage systems are critically needed and recognized as one of the essential parts of the renewable-energy based multigenerational systems due to intermittent availability of renewables. They also help to manage the energy supply and demand profiles.
- Nuclear energy: Nuclear energy is expected to play an important role in meeting the societies' energy need in a clean way. In this regard, small-modular nuclear systems are expected to meet the electricity demand of the communities along with various other types of useful commodities, including heat, cooling, hydrogen, clean fuels, etc.
- Waste to energy technologies: Wastes should first be recycled as much as possible at their sources and converted in useful forms for further utilization. If they are not recycled accordingly, waste to energy technologies are necessary to convert such wastes into useful forms of energy and fuels by deploying various methods ranging from gasification to pyrolysis.
- Multi-objective optimization studies: Building multigenerational and renewable energy-based systems requires high costs. Also, in order to design the systems, their operation periods, conditions should be adjusted well. For all of them, it is required to perform a multi objective optimization to better design and build the systems for operation.
- Real-time automation and control technologies: In order to operate the systems in the optimum desirable conditions, there is a strong need to develop real-time automation and control technologies to implement accordingly and manage the demands and supplies in an effective and efficient manner.

1.6 3S Concept

Energy has been, is, and will be a significant need in people's lives. Energy consumption in the world is ever-increasing significantly. Today, energy demands are generally met by fossil-fuel-powered systems. Since fossil-based fuels bring some risks, have limited and nonhomogeneous reserves, and results in environmental impacts and energy security concerns, people have oriented toward alternative energy sources. In the deployment of renewables as alternative and clean energy sources, despite their major advantages in terms of energy security and environmental friendliness as well as sustainability, there is still a challenge, due to the fluctuating nature of some renewables, namely solar and wind. In order to overcome such a challenge, there is strong need to develop right energy storage (ES) solutions for implementation. ES techniques primarily have a great potential to solve the discontinuity of renewables. The second biggest issue in the use of energy is an unbalanced energy demand profile and hence fluctuating nature of it. In this regard, ES methods have the potential to balance energy supply and demand profile periods.

ES has many methods and different applications. A conventional energy conversion system consists of a source, a system, and a service. Over time, each of the above elements has improved significantly with the developing technology. In order to reduce carbon emission and environmental impact, renewable energy sources have been integrated the energy conversion systems. Also, multigeneration systems have been started to use in the system for increasing the useful outputs of the system.

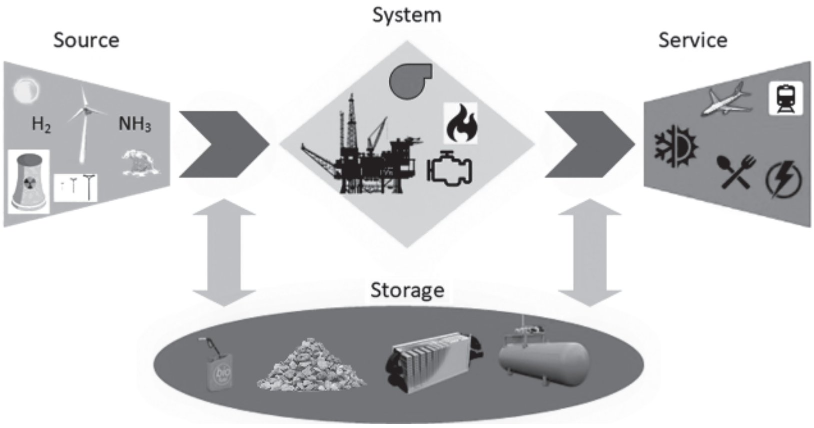


Figure 1.7 The rule of 5S (5S = 3S + 2S) in the respect of energy domain.

These changes have played a very critical role in better sustainability. However, energy production and demand profiles do not always match. The energy demand profile shows fluctuating nature over a time frame. As expressed before, to meet peak loads require additional power plants or the energy imports, and so it requires a high cost. Also, the ever-increasing use of wind turbines and their increasing contribution to nighttime electricity generation will bring about a rising nighttime surplus of electricity generation. This causes waste energy, which is produced by wind turbines. Nuclear power plants also have a similar situation. ES has a high impact on recovering waste energy. Figure 1.7 demonstrates a novel aspect of energy conversion systems. Integrating ES to the conventional energy conversion system, between the source and system, and the system and service reduce the waste energy and solves the mismatch between the energy production and demand periods. This rule is called as 3S + 2S = 5S. The rule of 3S + 2S presents a higher efficiency for energy systems and a better sustainability for communities.

1.7 Role of Engineering

Although there are many definitions of engineering, we define engineering as "creating the optimum solutions for physical problems and challenges with new ideas or innovative techniques." As highlighted earlier, the biggest problems of today are energy and environmental related as both are affecting the other parameters such as economy, transportation, etc. as mentioned in Section 1.1. Although engineers are responsible for solving the problems in all sectors, they are firstly responsible for finding the optimum and cost effective solutions to energy and environmental related problems, considering each step of the rule of 5S. They need to find a secure, reasonable, efficient, and reliable way to benefit from any clean energy source. Then, they develop systems considering life cycle, economy, and efficiency. Finally, they will meet the demands considering energy recovery and demand side management tools. It is really needed to perform those in a smart way as demonstrated in Figure 1.6.

Note that everything engineers do as practicing technical staff can have an impact on the environment. Engineers are further responsible for, or are involved in technology development and deployment as they do designs, analyses, developments, buildings, and implementations. For an engineering system, the following are three key activities of work.

Material selection: One may ask the following questions for material selection: Can we use environmentally friendly alternative materials? Can we use less amount of materials without compromising the functionality or reliability? Can we use recyclable materials? Can we obtain the raw materials in a green way? For example, aluminum-based materials are used in many sectors from automotive to construction, energy to electronics. Regrettably, most of them are not adequately recycled after they complete their lifetime or use period. More importantly, one may need to note that aluminum may not be needed for every targeted application or process or system. Therefore, correct material selection should be performed by considering its recyclability, cost, advantages, and disadvantages. The key to doing this is knowing the features of the materials. As another example, nanoparticles are used in many applications to enhance system performance. However, nanoparticle production requires some chemicals and high energy. So, when a nanoparticle is used in any application, its environmental impact and cost should be considered. The benefits expected from nanoparticles should be higher than the ones consumed during nanoparticle production.

Process selection: Here, process selection is specifically targeted for production and manufacturing stages where processing the raw materials to transform them into a final product is a key objective. In most cases, every step releases waste materials to the environment as air pollutants and solid wastes. All sectoral processes and activities require energy and material input(s) and produce some outputs with wastes. Therefore, an optimum process should be designed and implemented to reduce the energy and material inputs, maximize the useful outputs, and minimize the wastes.

Energy selection: All raw-material obtaining and production stages require energy along with all production activities. Therefore, it plays the most crucial role in environmental impact. The quantities and the types of energy we use directly affect environmental quality. Energy input should be selected depending on the type of demand. For example, when hot water is needed, boiling water by burning natural gas will not be the logical technique in an environmental manner. Or, when you have exhaust gasses with a temperature of 300°C, exhausting it without recovering heat will not be the effective solution. Consequently, both needs and energy input(s) should be considered carefully by taking into consideration energy recovery options.

For example, let's investigate ammonia production, which is one of the most produced chemicals all around the world. Hydrogen and nitrogen should be provided as the raw materials, with a couple of chemicals used as catalysts for the ammonia synthesizer. Today, nearly all hydrogen for ammonia production is provided by a fossil-based source, mainly natural gas. So, to be engineers, we need to include green hydrogen in our ammonia production facility. Nitrogen is generally obtained via air separation techniques which require high energy input. So, in order to reduce the environmental impact of air separation, we need to use renewables and/or develop a method for air separation that requires less energy input. All ammonia production facilities use a traditional technique called the Haber-Bosch, which has low efficiency. So, again, as to be engineers, we are responsible for developing the cycles and chemical reaction chains for more efficient ammonia production. Civil engineering can be part of this facility with sustainable materials. Software engineering can work on better management and autonomous control coding. Consequently, there are many opportunities in all engineering fields for more sustainable ammonia production.

As today's systems, machines, and devices require energy input and management, many programs specialize in energy-related studies in higher education, from civil to electronic, environmental to planning, and mechanical to software engineering programs. Today, energy and the environment should be part of all programs as our globe requires urgent acting.

1.8 Life Cycle Assessment

Impact of the energy systems on the environment is today clear for everyone. However, not only energy systems cause the environmental problems. Almost all activities in all sectors have impact on the environmental impact categories. In order to assess systems in terms of their environmental impacts, life cycle assessment (LCA) is an essential tool. LCA provides a picture of how engineering decisions in any particular field for building and producing goods to serve society affect the environment. All stages of a product's life cycle must be considered in finding ways to reduce environmental impacts by generating clearer and more efficient manufacturing operations (with less energy and materials inputs) and recovering energy and materials during the waste management. LCA is a significant tool in implementing the concepts of green design, green power use, and waste minimization. Therefore, it can be used in any sectors and any applications.

Figure 1.8 illustrates a process layout of the life cycle assessment. In LCA analysis, the system boundaries should be defined carefully. In other words, it must be determined which parameters, processes, inputs and outputs will be included in the analysis. Normally, it is expected that to include everything for a system/process/manufacturing in the LCA, from raw-material obtaining to waste disposal, the lifetime of the product is considered. Thus, we can see the full picture of the system in terms of environmental impacts. Then, we can choose what can be implemented to the system in order to enhance their environmental impacts.

Figure 1.9 demonstrates the conventional (linear) economy and circular economy for the vehicles. In the linear production and consumption economy (Figure 1.9a), raw materials are used for production. Then, products are reached to user with a distribution network. Users use the vehicles until the vehicles complete their lifespan. The vehicles go to junkyard as the waste. In circular economy (Figure 1.9b), every item in production and consumption periods have a great impact on the LCA of the vehicle. A circular economy aims less waste output and emissions releases. Each step should be carefully studied in terms of LCA.

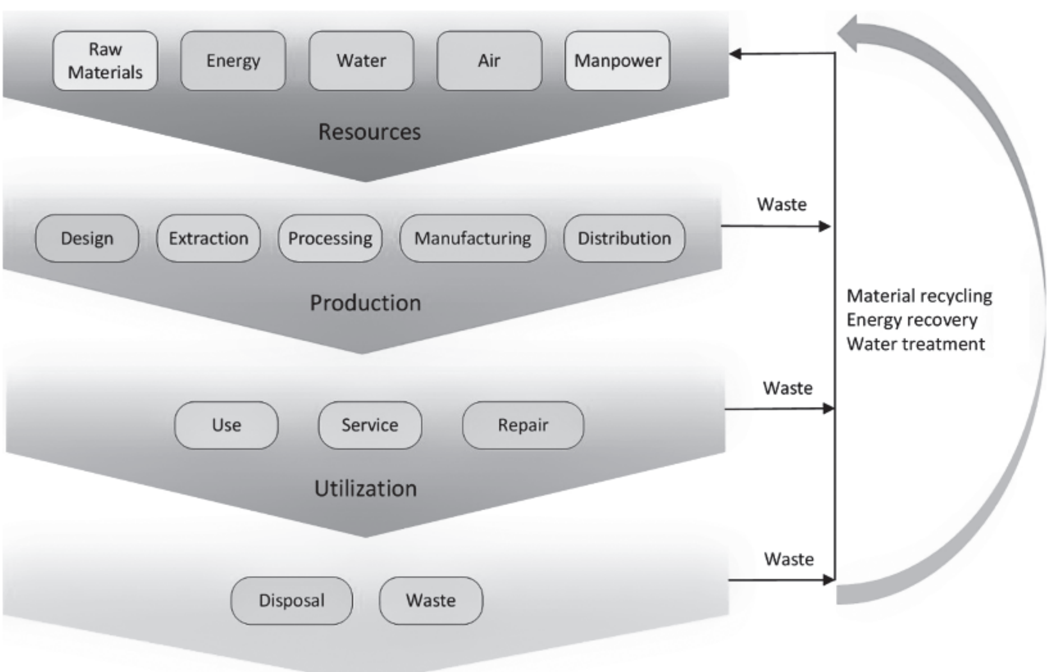


Figure 1.8 A system layout for the life cycle assessment.

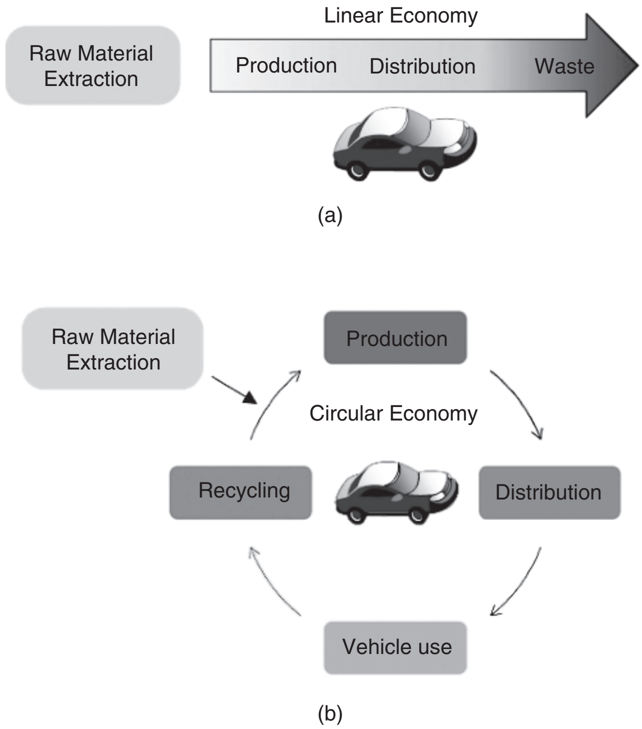


Figure 1.9 Two specific views of the life cycle of the vehicles: (a) linear economy and (b) circular economy.

As another interesting example, the heat transfer enhancement techniques are considered a common way to improve the thermo-fluid performance of heat exchangers and burners. In order to enhance the heat transfer, many methods have been introduced and implemented in practical applications. It is clear that enhanced heat transfer will help reduce energy consumption and emissions depending on it. However, sometimes the emissions emitted during the manufacturing and operating the technique developed to improve the heat transfer may be higher than the cases without enhancement or with another option. So, it is really needed to perform a complete analysis considering all performance criteria such as thermodynamics, heat transfer, fluid flow, economy, environmental impacts, etc.

In order to perform a complete LCA, there is a need to seek responses for the following questions:

- What raw materials to use?
- Where to order these materials from?
- What types of energy to use in production?
- How to transport the products to customers?
- How to recycle the materials?
- How to dispose of the wastes?

While seeking the responses for these questions, the key criteria must be minimizing the cost and environmental impacts and maximizing the product quality and efficiency.

The following key steps, shown in Figure 1.10, should be followed in the LCA analyses and studies:

- Goal and scope definition
- System boundary identification
- Inventory analysis

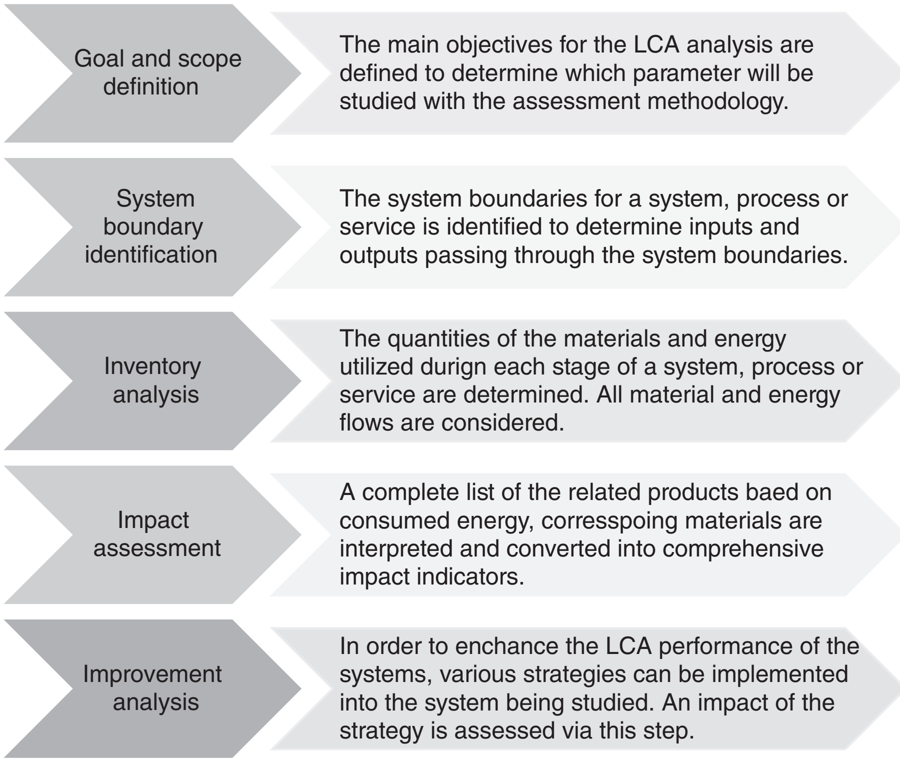


Figure 1.10 The steps of a complete life cycle assessment.

- Impact assessment
- Improvement analysis

The first two steps are more introductory, but considered important ones for achieving a consistent LCA analysis as they define the objectives of the analysis and the boundary of the system. The boundary of the system can be mainly defined as cradle-to-grave and cradle-to-gate. Some conventional LCA studies may include these two first steps combined. In either way, they are important to handle properly depending on the system chosen. The next one is inventory analysis which covers the identification of materials, systems, equipment, devices, etc., used in the system. For this step, some libraries and databases, which are readily available in the literature and the LCA software, are used. This is then followed by the impact assessment which is performed based on the inventory analysis by considering the objectives. Finally, the improvement strategies are implemented to enhance the system's performance and reduce the environmental impact categories.

Illustrative Example 1.1 Let consider the life cycle costing (LCC) analysis and comparative assessment of the lighting, incandescent, compact fluorescent and LED (light-emitting diode) bulbs. Note that incandescent bulbs are less expensive (but converting 95% to heat and 5% to usable light). Compact fluorescent bulbs are obviously much more energy efficient. In addition, we have LED bulbs which are even more efficient than compact fluorescent bulbs. So, let's look at which type of lighting comes out top in the LCC analysis.

Results and Discussion

Table 1.1 demonstrates the benchmark for both lighting bulbs. It is clear from Table 1.1 that only unit price of the bulbs is considered, incandescent bulbs are three times cheaper than compact fluorescent ones and six times cheaper than LED ones. However, when we consider the lifespan of the bulbs, for the same lifespan period which is 50,000 hours, while fifty incandescent bulbs

Table 1.1 The benchmarking for incandescent bulbs and compact fluorescent bulbs. *Source:* Feit Electric.

Cost of Buying Bulbs	**Incandescent** 	**Compact Fluorescent** 	**LED** 
Lifetime of one bulb (hours)	1,000	10,000	50,000
Bulb price ($)	2	6	12
Number of bulbs required for 50,000 operating hours	50	5	1
Cost of bulbs ($)	50 × $2 = $100	5 × $6 = $30	1 × $12 = $12
Energy cost			
Equivalent wattage (W)	75	20	12
Watt-hour (Wh) needed for lighting for 10,000 hours	75 × 50,000 = 3,750,000Wh =3,750 kWh	20 × 50,000 = 1,000,000Wh =1,000 kWh	12 × 50,000 = 600,000Wh =600 kWh
Cost at $0.05 per kWh	3,750 kWh × $0.120 = $450	1,000 kWh × $0.120 = $120	600 kWh × $0.120 = $72
Total Costs ($)	$100 + $450 = $550	$30 + $120 = $150	$12 + $72 = $84
Environmental impact	3,750 kWh × 1 kgCO_2/kWh = 3,750 kg CO_2	1,000 kWh × 1 kgCO_2/kWh = 1,000 kg CO_2	600 kWh × 1 kgCO_2/kWh = 600 kg CO_2

and ten compact fluorescent bulbs are required, one LED bulb is needed. Also, when their energy consumption is taken into consideration for the operating hours of 50,000 hours, they are $100, $30 and $12, respectively. Namely, while the compact fluorescent bulb reduces the lighting costs by 3.33 times, LED bulb reduces it 8.33 times. Lastly, thanks to the decreasing electricity consumption, the CO_2 emissions therefore reduce significantly. Consequently, despite the fact that the unit price of the LED bulbs are higher than the compact fluorescent and incandescent bulbs to build, the operating costs and environmental impacts of LED bulbs are drastically lower than compact fluorescent and incandescent bulbs.

Illustrative Example 1.2 Compare the amount of CO_2 emission for transportation to the Ontario Tech University campus with different types of vehicles:

Let us consider a student who daily comes to the Ontario Tech University campus from the residence/home which is about 20 km away from the campus. Calculate the amounts of CO_2 emissions of the transportation per day for the following cases: vehicle I: gasoline, vehicle II: hybrid (gasoline and electric), vehicle III: plug-in hybrid, and vehicle IV: electric (either battery or fuel cell (hydrogen) based).

Results and Discussion

As we are consider the Ontario Tech University campus as final destination, the actual operational emission values for these four common types of passenger cars used in the Ontario, Canada are shown in Figure 1.11. As expected, gasoline-fueled car emits the highest CO_2 with the value of 158.2

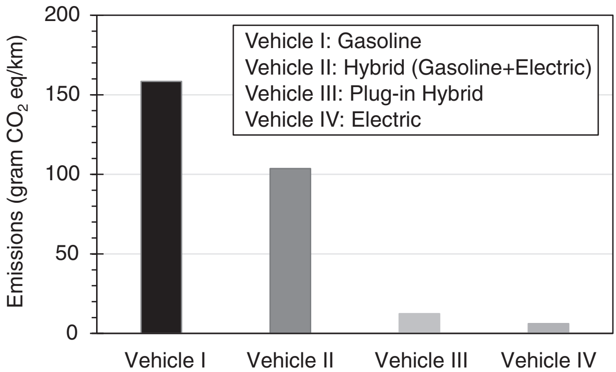


Figure 1.11 The emission values of the various vehicles using in the Ontario, Canada (data from [5]).

grams CO_2e/km. The hybrid vehicle (gasoline and electric) (HEV) emits 103.6 grams CO_2e per km. Plug-in hybrid vehicle emits 12.4 grams CO_2e per km. Finally, full electric powered one emits 6.2 grams CO_2e per km. Note that these values are for 45% highway and 55% city driving values.

For the student considered in this problem, total daily commuting emissions will be 6336, 4144, 496, and 248 grams CO_2e/km for each vehicle, respectively. Consequently, upgrading the vehicle from gasoline to hybrid vehicle will reduce the emissions 34%. It will be 92% for plug-in hybrid vehicle and 96% for electric vehicle. Here, it should be noted that the electricity production emission will be critical for plug-in and full electric vehicles. In this problem, Ontario's electric emission values is taken into consideration. For the hydrogen fueled vehicle, the main concern will be the method of the hydrogen production and energy source. When hydrogen is produced via electrolysis by using renewable energy sources, as hydrogen fueled vehicle doesn't emit any CO_2 emission, the emission for the student's car will be zero.

1.9 Industrial Ecology

The field of industrial ecology is now recognized as an emerging and challenging discipline for scientists, engineers, and policy-makers. Often termed the "science of sustainability." The multidisciplinary nature of industrial ecology makes it difficult to provide a consistent and universally accepted definition. Figure 1.12 depicts an illustration of the industrial ecology. It is promoted as an approach to close industrial production loops and reduce waste, thereby making better use of resources and preventing the overuse of raw materials. Industrial ecology aims at transforming industries to resemble natural ecosystems where any available source of material or energy is consumed by some organism. The managerial approach of industrial ecology essentially involves analyzing the interaction between industry and the environment, through the use of tools such as life cycle analysis (LCA).

Industrial ecology provides a comprehensive view of design for the environment. It is very popular for engineering design since it combines it with environment principles. It aims to minimize and eliminate the overall environmental consequences of engineering design decisions. Industrial ecology includes:

- Circulating and reusing the materials flows within the system with a minimum cost and effort effectively and efficiently,
- Reducing the amount materials used in products to achieve a particular function,
- Protecting living organisms by minimizing or eliminating the flow of harmful substances, and
- Minimizing the energy consumption and the waste heat to the surroundings which will also help reduce thermal pollution.

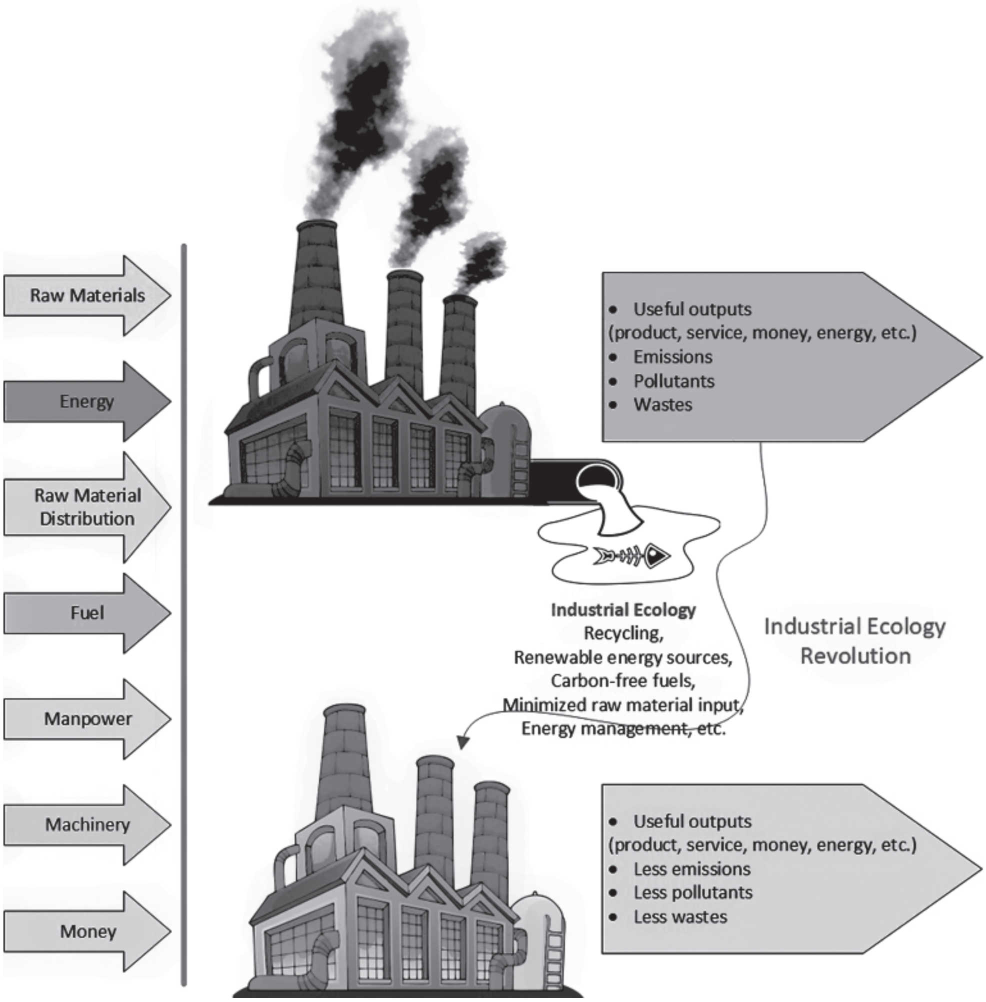


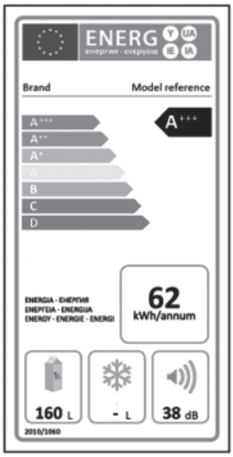
Figure 1.12 Illustration of industrial ecology.

In order to analyze any industrial ecology, performing environmental analyses based on LCA is not enough; energetic, exergetic, and economic analyses should be performed with it. Thus, it is possible to see an entire picture of the sustainability for any system, device, production process, service, etc.

1.10 Energy Labeling

In order to increase the use of energy-efficient devices and guide the customer in the market, many applications have been carried out such as energy efficiency labels. In Figure 1.13, the energy labels used in refrigerators, washing machines, and vehicles are shown. Such practices are both informative and encouraging to people. Since devices used in daily life such as TV, computer, refrigerator, air conditioner, washing machine, heater, etc. can be easily selected according to their energy-efficient situation, they have wide usage. Thus, it is possible to reduce energy consumption in residential buildings. Extending these labeling and grading applications to devices and applications which are consumed energy will play an important role in reducing energy consumption.

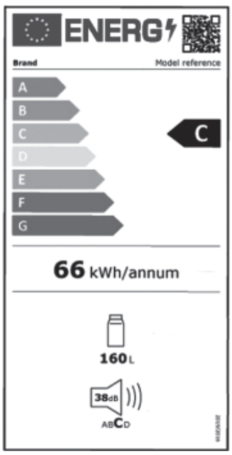
In the USA, the Energy Star symbol, which is the government-backed symbol for energy efficiency, is used for providing simple, credible, and unbiased information that consumers and businesses rely on to make well-informed decisions. Energy Star, and its partners, which are thousands



Current energy labels used in European Union countries.

These labels use in Fridges and freezers, dishwashers, washing machines, washer-dryers, electronic displays including televisions and lighting.

Source: Ref. [6]

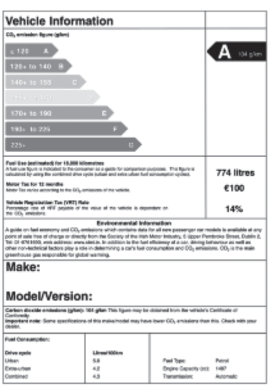


New energy labels will be used in European Union countries.

The label given above has been updated by European Commission as a result of the development of more and more energy efficient products, and because the difference between A++ and A+++ is less obvious to the consumer, the EU energy labels categories will be gradually adjusted to reintroduce the simpler A to G scale.

For example, a product showing an A+++ energy efficiency class could become a class B or lower after rescaling without any change in its energy consumption. The class A will initially be empty to leave room for more energy efficient models to be developed.

Source: Ref. [6]



A label for a gasoline-fueled vehicle, which indicated CO_2 emission, the different consumption if fuel (urban, extra urban, mixed)

Source: [7]

Energy Star symbol used in the USA

Source: [8]

Figure 1.13 Some common energy labels practically used in various countries around the world.

of industrial, commercial, utility, state, and local organizations, have provided saving in residential and commercial sectors more than 4 trillion kilowatt-hours of electricity and achieve over 3.5 billion metric tons of greenhouse gas reductions, equivalent to the annual emissions of more than 750 million cars. In only 2018, the Energy Stars and its members have helped to save $35 billion in energy costs in the USA [8].

In order to reduce emissions in the transportation sector in Canada, they have started to use energy labels on vehicles. Figure 1.14 shows the energy labels for gasoline- and hydrogen-powered vehicles. The label indicates the fuel consumption rate, yearly fuel cost and emission values. Thus,

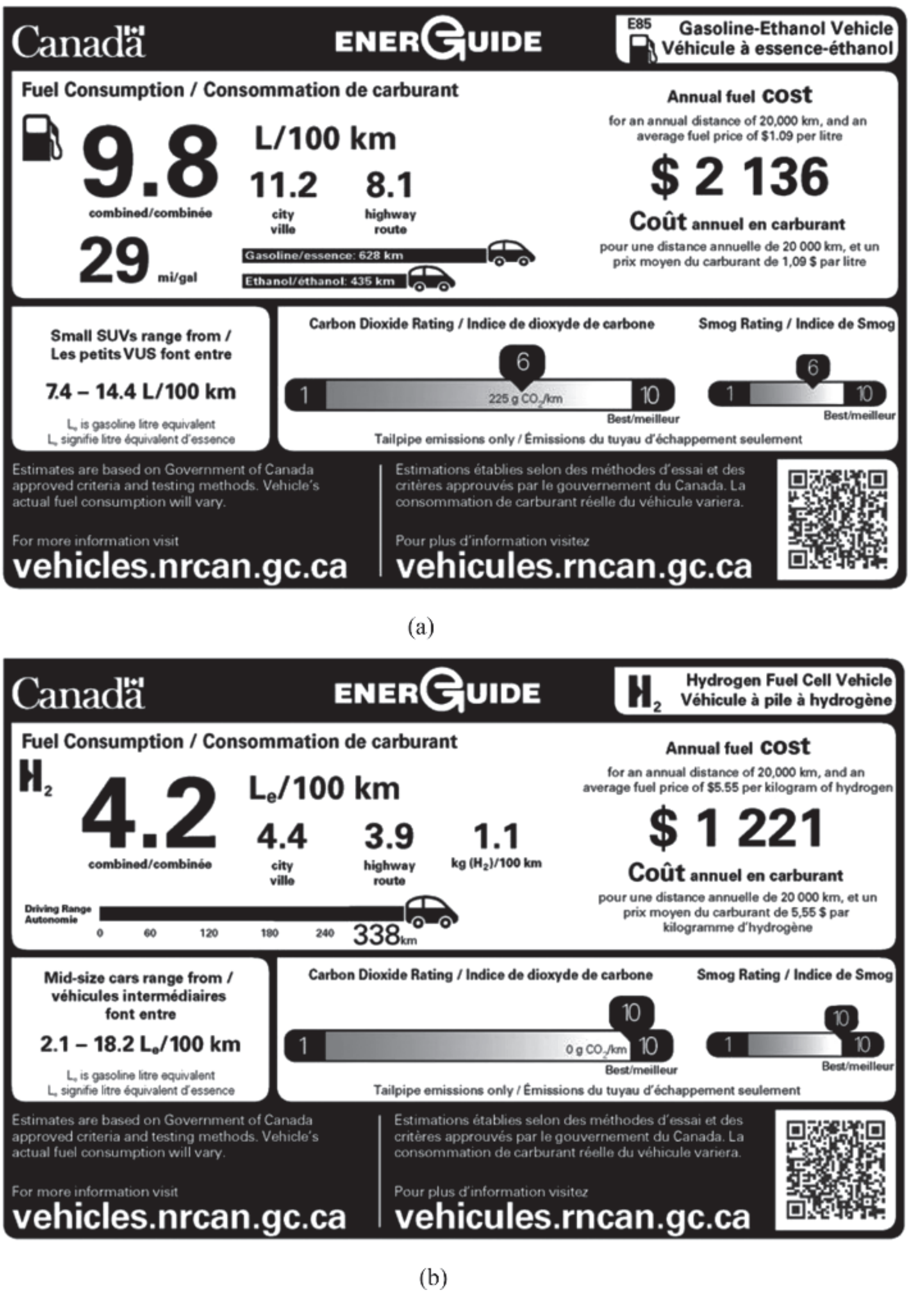


Figure 1.14 EnerGuide labels for (a) gasoline-fueled and (b) hydrogen-fueled vehicles in Canada (adapted from [9]).

they have created an awareness of the environmental effects caused by vehicles, by including encouraging impacts on fuel consumption and cost. Here, the potential of the hydrogen-fueled vehicles to reduce the emissions and cost is clearly seen in Figure 1.14.

The labeling is technically critical for every sector and provides a significant recognition and a meaningful information for selection of the right products as needed. Such a labeling is also very common in the food sector. Figure 1.15 shows the energy and contents label for a frozen lasagna for four people. It is clear for everyone that this kind of labeling provides the important information for the people to understand the contents and possible implications. These labels increase awareness to choose the right product for consumption. The bottom line here is that labelling has to be a prime responsibility for every product, system, service or application. For a sustainable future, the use of energy labels should be expanded for energy systems, buildings, products, services, etc. With the carbon taxes, the use of energy labels will probably be further increased. Figure 1.16 demonstrates a potential energy label for a thermal power plant. A label for a power plant summarizes all critical parameters for the entire system such as fuel type, fuel consumption rate, waste, energy recovery option, etc. Critical environmental impact categories should be included in the label. Thus, it is possible to understand how power generation systems work effectively. An energy label may consist of the following for per W, kW, or MW production, transportation, conversion, consumption, etc., but not limited to:

- Fuel type
- Fuel consumption rate
- Total energy input
- Total energy output
- Cooling/heating requirements
- Energy or exergy efficiency (or performance coefficient)
- Emissions (or environmental impact categories)
- Green category (i.e., out of 10)

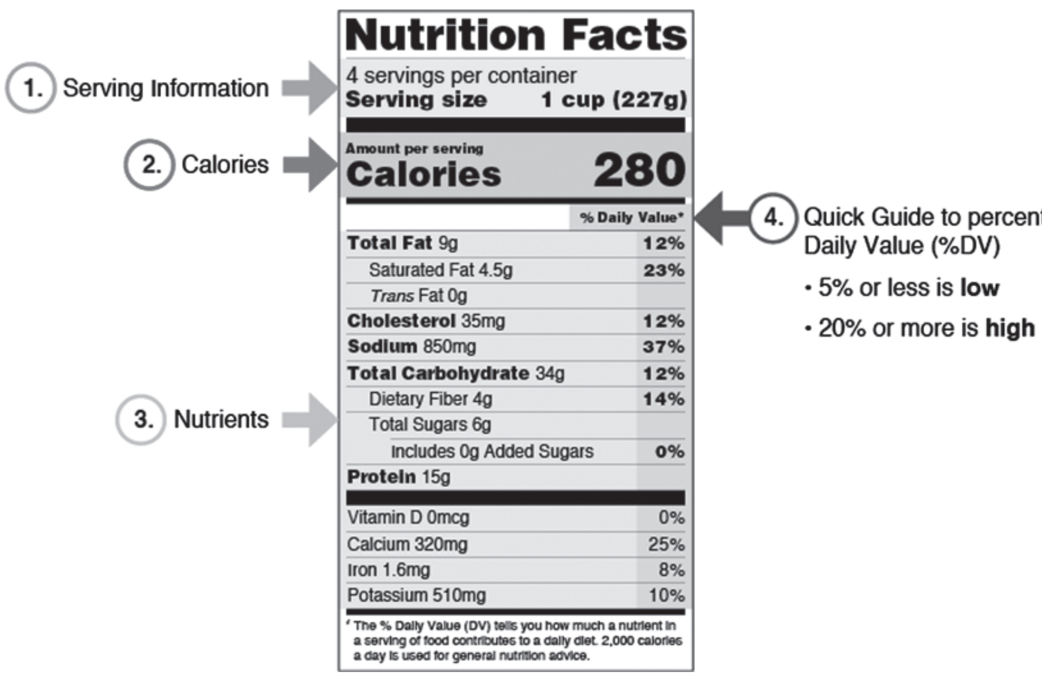


Figure 1.15 Nutrition facts label (adapted from [10]).

Thermal Power Plant Facts	
Fuel type:	......
Fuel consumption rate (kg/s):	......
Total energy input (MW):	......
Power output (MW):	......
Cooling requirement (MW):	......
Energy efficiency (%):	......
Heat recovery option (Y/N):	......
Heat rejection rate (MW):	......
CO_2 emissions (kg/MWh):	......
SO_2 emissions (kg/MWh):	......
NO_x emissions (kg/MWh):	......
VOC emissions (kg/MWh):	......
PM emissions (kg/MWh):	......
Ash (kg/MWh):	......
Ozone depletion potential (ODP):	......
Global warming potential (GWP):	......
Acidification potential (AP):	......

Figure 1.16 A potential energy label for a power plant.

1.11 Closing Remarks

This chapter deals with the energy and environmental perspectives. First, the importance of energy is presented with illustrative examples. Next, energy issues and environmental impacts are introduced and discussed from various perspectives. Then, some smart solutions to overcome energy and environment related challenges are introduced and discussed. The role of engineers in providing solutions is discussed. Finally, energy labels are introduced potentially for energy sector same as what is done in other sectors, such as food sector.

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Questions/Problems

Questions

1. Discuss the importance of energy with some examples.
2. Explain how global issues affect people's life?
3. Discuss the major environmental issues.
4. Discuss the projected CO_2 emissions from 2020 to 2050.
5. What is energy intensity? Explain with an example.
6. What are the key requirements in obtaining clean air, clean water and clean food?
7. Define each item in the concept of 3S+2S=5S.
8. Discuss the importance of the storage techniques in 5S rule with some practical examples.
9. What are the nine specific targets to achieve the smart solutions?
10. List the nine branches specific smart energy portfolio branches and discuss each in brief.
11. Discuss the role of engineering and its consequences.
12. What is life cycle assessment? and explain how to complete its key steps.
13. What are the six questions to perform a complete LCA analysis?
14. What is life cycle costing? and why is it required?
15. What is industrial ecology? Discuss its role and implications.
16. What are the main differences between linear and circular economy?
17. Why is energy labeling important? Discuss it with examples coming from our daily life.

Problems

1. There are various light bulb types where they have different energy consumptions and costs. Perform a comparative life cycle cost analysis and assessment for spotlight bulbs, halogen lamps, led strip lights. Use the information provided in the table below and fill the missing sections to make a life cycle cost analysis.

	Spotlight	**Halogen**	**LED strip**
			
Lifetime of one bulb (hours)	5,000	7,500	15,000
Bulb price ($)	5	4	12
Number of bulbs required for 30,000 hours	3	2	1
Cost of bulbs ($)	...	...	...
Energy cost			
Equivalent wattage (W)	20	60	20
Watt-hour (Wh) needed for 30,000 hours	...	...	...
Cost at $0.05 per kWh	...	...	...
Total Costs ($)	...	...	...
Environmental impact (1 kgCO_2/kWh)	...	...	...

Sources for table images: OSRAM GmbH/Koninklijke Philips N.V./BAZZ SMART HOME.COM

2 Make a comparative emissions analysis for the four modes of daily transportation from home to school, such as diesel fueled vehicle, pneumatic vehicle, electric vehicle and hydrogen vehicle (similar to the example given illustrative example 2). Discuss how more carbon dioxide emissions reduction will be possible if there are public gasoline fueled and electric buses used for about 50 students instead of using individual cars.

3 Consider that the diesel-fueled bus consumes 20 liters of diesel per 100 km and emits 400 grams CO_2eq/km. The hydrogen based electric bus consumes 2 kWh/km where hydrogen is produced by renewable energy sources in a clean manner. Compare the calculated results with the results presented in illustrative Example 1.2.

4 Make an example about industrial ecology based on the criteria presented for a product selected and discuss pros and cons.

5 Identify energy labels available for at least five different commodities (including household appliances) and see what criteria each label considers. Discuss them comparatively.