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Evaluation and Optimization of Strategies to introduce Renewable Energy into Electricity Generation for Housing

Maya Julian Salame

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Evaluation and Optimization of Strategies to introduce Renewable Energy into Electricity Generation for Housing

THÈSE

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en

**Automatique, Traitement du signal et des images, Génie
informatique**

par

Maya JULIAN

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Abstract

This thesis falls within the context of the energy transition in Lebanon motivated by the country's commitment to the efforts leading to sustainable development around the world. This energy transition must be prepared by simultaneously considering several parameters such as the costs related to the acquisition of each type of energy source, consumption, maintenance as well as the costs related to the public health. The objective of the thesis is to improve the existing strategies of electricity production using micro-grid systems that integrate renewable energy sources. An analytical model was developed in order to establish an economic plan for energy production taking into account various operational and environmental constraints. This plan is based on a strategy which consists in switching between two energy sources taking into account the acquisition and maintenance costs associated with each type of energy and the impact on the public health. An example is presented in order to show the robustness of the developed analytical model. The two energy sources considered are diesel generators and solar energy. Finally, a field study was carried out. It was concluded that achieving the objectives of energy transition in Lebanon must necessarily go through the increased use of renewable energies for residences and transportation.

KEYWORDS: Micro-grid, Energy efficiency, Diesel generators, Renewable Energy, Environmental impacts, Sustainable development, Air Pollution.

Résumé

Cette thèse s'inscrit dans le contexte de la transition énergétique au Liban motivée par l'adhésion du pays aux efforts menant vers un développement durable à travers le monde. Cette transition énergétique doit être préparée en tenant compte simultanément de plusieurs paramètres comme les coûts liés à l'acquisition de chaque type de source d'énergie, la consommation, la maintenance ainsi que les coûts liés à la santé des citoyens. L'objectif de la thèse consiste à améliorer les stratégies existantes de production d'électricité en utilisant des systèmes micro-réseau qui intègrent des sources d'énergies renouvelables. Un modèle analytique a été développé afin d'établir un plan économique de production d'énergie tenant compte de diverses contraintes opérationnelles et environnementales. Ce plan est basé sur une stratégie de permutation entre deux sources d'énergie tenant compte des coûts d'acquisition et de maintenance liés à chaque type d'énergie et de l'impact sur la santé des citoyens. Un exemple est présenté afin de montrer la robustesse du modèle analytique développé. Les deux sources d'énergie considérées sont les générateurs Diesel et l'énergie solaire. Une étude de terrain a enfin été réalisée. Il en est ressorti que l'atteinte des objectifs de transition énergétique au Liban doit nécessairement passer par l'utilisation accrue des énergies renouvelable pour le résidentiel et le transport.

MOTS CLÉS: Micro-réseau, efficacité énergétique, générateurs diesel, énergies renouvelables, impacts environnementaux, développement durable, pollution atmosphérique.

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GENERAL INTRODUCTION

At the present time oil prices become considerably expensive and CO₂ emissions increase rapidly, grid operation is becoming even more multidimensional given the environmental policies that are enforced. Given the set of goals arising from the Kyoto agreement and initiatives like the 20/20/20 European agreement, tight schedules and boundaries are dictated, for all the participating countries in order to consistently reduce their Greenhouse Gas (GHG) emissions while integrating more renewable energy and substituting older and pollutant heavy production technologies with newer and more eco-friendly ones.

Thus, the whole restructuring of the energy systems are focused in two fronts in order to achieve the mentioned goals, "cleaner" energy integration and energy efficiency.

In order to achieve cleaner energy, attention has been drawn to the highly promising Renewable Energy Sources (RES), Combined Heat and Power (CHP) units and alternative fuels like natural gas units and Fuel Cells (FC).

The installation of additional units of Dispersed Production sources-DPS (PV, WT, FC, Micro_CHP, etc.) close to consumers leads to a new era for the Energy Systems. Micro-grids could come into play to aid the network through CO₂ emission reduction while increasing their efficiency through local generation.

Micro-grids are defined as Low Voltage (LV), or in some cases Medium Voltage (MV), networks with DPS, together with storage devices and controllable loads (e.g. water heaters, air conditioning) with a total installed capacity in the range of few kW's to couple of MW's. The unique feature of Micro-grids is that, although they operate mostly interconnected to the upper level voltage distribution network, they can be automatically transferred to islanded mode in case of faults in the upstream network.

This thesis aims to develop methodologies and analysis techniques based on numerical study for the quantification of the advantages of integrating Micro-grids in residential applications. Moreover, suitable calculation model on Matlab has been developed for verification and comparison in Energy consumption costs between Diesel Generators and the Micro-grid.

This report is composed of 4 chapters described below:

The first chapter is a state of the art that describes the different produced types of air pollution e.g. Indoor and Outdoor, and their impact on the environment, health, economy and development of ecosystem.

Indoor air pollution and their presence in our surrounding environment, work area and homes, was explained with their symptoms that appear as fatigue, eye-nose irritations and the most common illness the asthma. Outdoor air pollution classified as “The great killer of our age” were also studied in details and its main causes were given as: Agricultural activities, mining operations, Exhaust from factories and industries, burning of fossil fuel.

For both sources of emission (indoor and outdoor), short- term exposure has related with transitory respiratory diseases and a high rate of hospitalization, while long-term exposure leads to chronic asthma, pulmonary insufficiency, cardiovascular diseases and cardiovascular mortality. Another important matter discussed in this work is the impact of air pollution on the society’s economy and the influence on their sustainable development.

In this chapter we have paid a particular attention to the causes of air pollution in Lebanon, where the citizens are facing dangerous and serious problems related to air pollution, to notice that this issue became more complicated with time especially when the government is not taking actions toward any kind of solution. The best example of this massive long term problems is Beirut the capital of Lebanon which is facing a non-controlled urbanization. Also we have exposed in this chapter 1 the problem of Public Transportation sector that almost does not exists in Lebanon, thus citizens depend on their own cars for moving which leads to a high traffic flux on the roads and increase in the percentage of nitrogen oxides, in addition the large number of old cars kept in circulation and the low quality of fuel used lead to the amplification of the pollution problem.

The particular case of air pollution in Lebanon produced by Diesel Generators (DG) were covered, where these power generators are responsible for the production of Carbon dioxide (CO₂), nitrogen oxide (NO_x) and particulate matter. Last in this chapter we have highlighted the pollution source coming from solid and organic waste and the illegal dumps of waste that do not respect fit the international norms in terms of health and environment.

In chapter 2 we have focused on Energy demands and available sources in Lebanon where 98% of its energy requirement is imported, thus investing in Renewable Energy Technology (RET) can be of high interest for the economic and social prosperity, especially that Lebanese society is facing many difficulties from the high level of pollution resultant from the fuel energy use. Main sources of Electricity production in Lebanon, Electricité du Liban, EDL (Public Sector) and Diesel generators (Private Sector), were studied and discussed in details in order to understand the existing weakness and problems of each sector. It has been concluded that EDL is operating at 95% with Fuel oil and the private diesel generators run completely with diesel,

where both are a consistent source of air pollution in the country. Thus the necessity of integrating renewable resources is a must and only solution to reduce the pollution emissions. Chapter 3 purposes are to provide a full scientific analysis to the actual state of the electric sector in Lebanon emphasizing on its negative impact on air pollution and on the development of factories and small enterprises.

Renewable energy in Lebanon and specifically hydraulic energy were planned to cover the full national need of electricity where 41.5% of the Lebanese electricity was produced from hydroelectric stations until the beginning of the 70's. Later a regression has been noticed in this clean production due to the instability in the political regimen where electric plants and networks suffered from destruction, aging, increased demand, hacking and many other deterioration factors. The last mentioned troubles turned the electric sector in Lebanon to a major problem at economic and environmental level. Problem with the electrical sector is essentially due to the old networks easily hacked, strong reliance on fuel-based electricity, which leads to an increase in air pollution without meeting the energy consumption demand. The underproduction of electrical energy leads to the development of a parallel electrical private sector also based on fuel burning what worsened air pollution problems despite all the measures taken by the governments to switch to greener electricity production. Finally a case study for electricity consumption in different locations in Beirut is realized and numerical analysis prove that shifting from fuel to solar production controlled by a Micro-grid will decrease the economic impact of electricity.

Chapter 4 treats the matter of Energy efficiency in Lebanon that became also a major issue during the last decade for reducing CO₂ emissions and limiting the energy dependence on the fuel-oil of the country. The energy efficiency policy in Lebanon remains relatively modest despite the great potential for energy savings in all consumption sectors. Good to mention that several initiatives have been taken to disseminate the use of solar water heaters, including direct financial aid under conditions and loans at zero interest.

To encourage the implementation of energy efficiency and renewable energy projects in Lebanon, many financial mechanisms have been established, in collaboration with the European Union and the association of Lebanese banks. Funds were proposed for loans at very low or zero interest rates to finance projects in the various sectors, particularly the industry for smooth switching to clean energy sources.

CHAPTER I: CAUSES AND IMPACTS OF AIR POLLUTION ON INTERNATIONAL SOCIETY.

Abstract

In this chapter, the sources of Indoor and Outdoor air pollution is discussed and an overview is given about their impact on the environment, health, economy and development of ecosystem, in addition to possible solutions. Most of the studies concluded that for both indoor and outdoor, time exposure to air pollution determines the symptoms and diseases that affect humans. Sources and causes of indoor and outdoor air pollution have been summarized, analyzed and discussed.

Air pollution is of direct relation with the ratio of mortality and morbidity, emitted from Natural and Man-made sources and released to atmosphere, with values exceeding the norms, as Ozone (O₃), nitrogen oxides (NO), carbon monoxide and dioxide (CO and CO₂), volatile organic compounds (VOCs) and particulate matter (PM).

Lebanon was taken as a case study where air pollution reached a dangerous level on the environment and public health, due to lack of measurement that must be taken by the government.

1. 1 Introduction

Air pollution occurs when any harmful gas, dust or smoke enters into the atmosphere and negatively affects the lives of humans, animals and plants. Moreover, air pollution is found everywhere around us in the air we breathe, the water we drink and it can be either natural or man-made.

In this chapter, we will discuss, analyze and give our observation and possible solutions concerning the different produced types of air pollution e.g. Indoor and Outdoor, and their impact on the environment, health, economy and development of ecosystem. Also we will deliberate the indoor air pollution and their presence in our surrounding environment, work area and homes, where it has been noticed that their symptoms appear as fatigue, eye-nose irritations and the most common illness the asthma. We have perceived that time exposure to the indoor air pollution plays a major role in the kind of the disease, where for a long exposure the mostly occurring health problems are respiratory sickness, heart problems and cancer. The 14 sources of indoor air pollution have been summarized and fully analyzed during this work. Concerning the outdoor air pollution most of the realized scientific studies have classify it as “The great killer of our age”, with the presence of more than one substance above the natural

limits in the breathed air, and it has been recognized that the main causes of outdoor air pollution are: Agricultural activities, mining operations, Exhaust from factories and industries, burning of fossil fuel.

For both sources of emission (indoor and outdoor), short- term exposure has related with transitory respiratory diseases and a high rate of hospitalization, while long-term exposure leads to chronic asthma, pulmonary insufficiency, cardiovascular diseases and cardiovascular mortality.

Also it has been deduced an increasing relationship between mortality/morbidity rate and air pollution concentration. Another important matter discussed in this work is the impact of air pollution on the society's economy and the influence on their sustainable development.

The present century has accomplishing a serious progress in various fields, specifically in technology, medicine and environment, however and regardless of the rapid progress that we have attained there were remaining many unsolved parts, that affect the Societies Health, in general related to the pollutions and namely air pollution.

Air pollution occurs when any harmful gas, dust or smoke enters into the atmosphere and negatively affects the lives of humans, animals and plants. These harmful particles are the consequences of many human activities which are present in the surrounding areas (indoors and/or outdoors).

Air pollution causes have different sources, e.g.: indoor air pollution, agricultural activities, mining operations, exhaust from factories and industries, burning of fossil Fuels.

According to different studies the sources of air pollution can be classified in two types of sources:

- **Natural sources**
- **Man- made sources.**

Natural sources of air pollutants are emitted from the combustion of various inflammable objects, gases released from biological decay, lightning strikes, dust carried by the wind from many pollutant sources (Volcanoes, massive forest fire, etc...).

Man-made sources of air pollution originate from smoke released from factories, vehicles, diesel generators, etc... These are considered destructive and highly toxic gases, as they contribute to the depletion of the Ozone layer. Furthermore, the reactions of certain gases, chemicals and the waste buried in landfills generate methane, which is extremely flammable.

Tropospheric ozone (O₃), nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs) and particulate matter are the most common air pollution that exceeds the norms and regulations in many countries and affects health according to WHO.

Although the technological growth advantages on our daily lives have widely improved our life conditions, yet we can't dismiss the fact that pollutions problem have reached a great extent.

Considering that urbanization and industrialization is linked to a strong and advanced economy, it has been thought that the developing countries are facing the biggest air pollution problems. But, a recent study showed that from the 3 million deaths around the world related to air pollution 87% occur in low- middle income countries like Western Pacific, and South East Asia, China and India and the 13% rests of these deaths occur in high- income countries like Europe, the Americans, West Pacific and Eastern Mediterranean [1], [2].

Lebanon is Middle East country categorized under developing countries. The Lebanese citizens are facing dangerous and serious problems related to air pollution, where this issue became more complicated with time especially when the government is not taking actions toward any kind of solution. The best example of this massive long term problems is Beirut the capital of Lebanon which is facing a non-controlled urbanization.

Public Transportation sector in Lebanon is almost nonexistent, thus citizens depend on their own cars for moving which leads to a high traffic flux on the roads and increase in the percentage of nitrogen oxides, in addition the large number of old cars kept in circulation and the low quality of fuel used lead to the amplification of the pollution problem.

Note that during the civil war the infrastructure of the electrical sector was destroyed which forced the Lebanese to rely on the diesel generators (DG), where these power generators are responsible for the production of Carbon dioxide (CO₂), nitrogen oxide (NO_x) and particulate matter that lead at the end to a very high rate of air pollution.

Another important source of pollution in Lebanon is the solid and organic waste produced by people, factories or companies. In 2015, Lebanon faced the garbage crisis where the waste were not collected for 9 months in Beirut and Mount Lebanon. This crisis led to having illegal dumps to place the waste in a manners that do not fit the international norms and all of this because we don't have a modern waste sorting factories [3], [4].

1. 2 Indoor air pollution

Air pollution is a combination of solid and liquid particles called aerosols, this chemical reaction leads to have a dirty air and this dirty air isn't found only outside our homes, schools, works, animal farms, we can have air pollution in the surrounding environment where we study, work or in our homes. Figure 1 describes a summary for different kinds of indoor air pollution sources.

Indoor air pollution can't be seen but sometimes it can be smell, it causes serious harmful problems in health, controlling these causes' means reducing the percentage of risk's health. Moreover, time exposure to air pollution influence the kind of disease affects the human, for short-term or immediate exposure to indoor air pollution, the symptoms are eye and nose irritation, fatigue, headache or what is known by Migraine, throat irritation and also asthma. To be sure whether these symptoms occur from exposure to indoor air pollution we must be aware to the time and place symptoms occur, such as if a person has asthma and when he leaves his home feels better than the problem is inside his house.[5], [6]

There can be more serious problems like respiratory sickness, heart problems and cancer, these effects occur when exposure to indoor air pollution without noticing for long time. Upon many studies approximately 2.2 million deaths per year due to indoor air pollution, moreover, the percentage is higher in developing countries with respect to indoor air pollution than developed countries since they are still using traditional ways in their lives, such as wood fuel and solid fuel, and for more confirming many studies showed that about 3 billion people around the world are using the above mentioned sources of energy in heating and cooking, so women are considered in the front line in facing these dangers since they spend most of their times inside houses and we can find such cases in Africa and Asia, but of course this doesn't mean that the developed countries are not facing the danger of indoor pollution since they spend most of their times between home and work. Like in the U.S the tobacco and radon are most causes of indoor air pollution they are facing.[7][8]

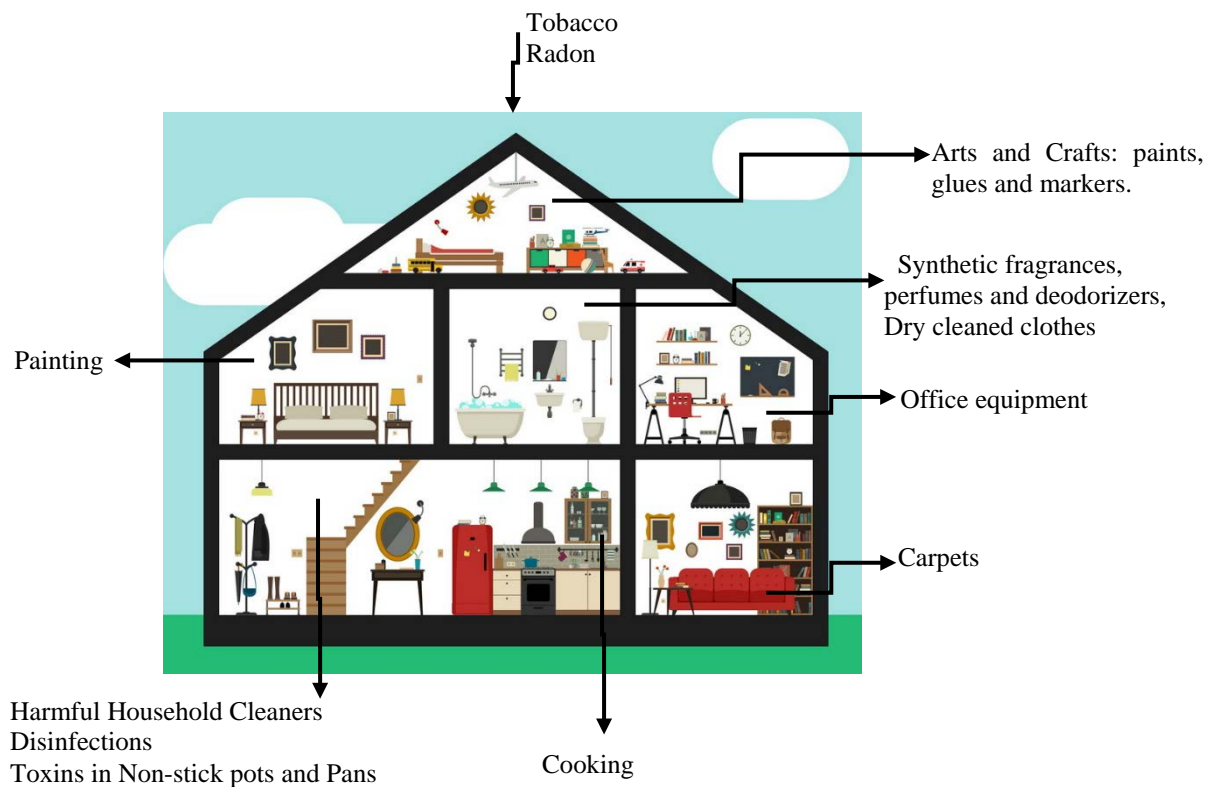


Figure 1: Different sources of indoor air pollution.

Sources of indoor air are many and maybe we are in daily contact with, but without noticing their damages or dangerous on our health [5], [9]–[11]:

1.2. 1 Cooking:

Citizens in poor countries are more vulnerable to environmental pollution factors due to the inability of these countries to assure the needed conditions for healthy life. Solid fuels like biomass (wood or crop wastes) or coal that are used in cooking and heating on daily basis are the main reason for having high percentage of indoor air pollution which in turn have direct effect on women and children health since they spend most of their times inside homes. These pollutants have a well-known side effects that are harmful to health, such as chronic obstructive pulmonary disease (COPD), acute respiratory infections (ARI), and lung cancer [11][12], [13]. COPD is ranked between the first ten factors causing total global burden of disease which is the loss of healthy years of life such as lost to premature death, where according to the WHO there is an estimation of 1.6 million premature death per year. Moreover, children living in area using solid-fuel are vulnerable to have ARI with a rate of 2 to 3 times more than children living in socio- economic area. The same with respect to women who spend most of their times inside houses and cooking with biomass fuel have 2 to 4 times of COPD than women who live within healthy conditions. The mortality rate of women from lung cancer is high due to their inhalation of high levels of sulfur inside the homes and this is the case in China. What happened in London

in winter 1950 was due to the emitting of coal smoke from chimneys and as a result of this incident and similar ones, it is forbidden to use domestic coal in developed countries. Figure 2 shows a typical case for indoor pollution coming from cooking with biomass sources.



Figure 2: Indoor air pollution with direct effect on women cooking inside home by using wood source of energy (Flicker January 4, 2012).

1.2. 2 Modern buildings

Indoor pollution cannot be confined to developing countries only, but it is found in developed countries, despite many attempts to limit its increase. Modern building release indoor pollutants like mixture of volatile and semi-volatile organic compounds due to materials used in construction, furnishing furniture or other indoor activities.

Volatile organic compounds (VOC) are organic chemical compounds whose composition makes it possible for them to evaporate under normal atmospheric conditions of temperature (less than 250°C) and pressure.

Most of the VOCs are man-made chemicals that are categorized under 3 groups which are very volatile organic compound (VVOC), volatile organic compound and semi-volatile organic compound (SVOC). The vaporization degree is what determines the identity of the VOCs, the VVOCs boiling point is between 0°-100° mostly gases while VOCs and semi-VOCs boiling point is between 100°-250°.[7], [14]

Semi-volatile organic compound means the rate of vaporization is less but not the risk on health, it is found in food preservation and plastics, in general solvent for inks, waxes, paints and lacquers in addition to pesticides that have been used long-time till now where these

pesticides are considered essential for modern agriculture. Pesticides are chemicals used to kill insects, rodent, pests, termites, fungi and microbes indoor and outdoor. 80% of people who use pesticides are for indoor use and they can be found in many forms like spray, liquids, powder, balls, sticks and foggers. This product is very dangerous if not used in the correct direction. Flame retardants (chemicals that are used to decrease the percentage of burning materials) are an important source of SVOCs, it is found in furnishing, electronics and electrical devices, building and construction materials in addition to transportation products [7].

The very volatile organic compound is a pollutant but until now without specific definition, it is not so far from VOCs which are chemical compounds of carbon apart from carbon monoxide, carbon dioxide, carbon acid and metallic, the data collected about the VVOCs depend on the degree of vaporization. VVOCs are pollutants produced from materials used indoors where they emit chemicals that interact with each other's and lead to indoor air pollution.

The proportion of VOCs inside homes is higher than outside, this high proportion is due to many activities and products used inside any house such as building materials, furnishing, paints, varnishes, wax, wood preservations, these products release most of their formaldehyde after two years, in addition to cleaners, disinfectants, stored fuel and automotive products, also dry cleaning clothing most dry cleaners use chemical for cleaning the clothes which is known as perchloroethylene- and pesticides. VOCs problems are also faced at work or schools where there are large equipment such as copies and printers- laser printers release tiny particles that enter the human blood stream by burrowing deep within our lungs- graphics and craft materials like glues, permanent markers and adhesives [14].

There are several symptoms resulting from exposure to VOCs that each of us can recognize early before the health situation get worse such as headache, nausea, fatigue, allergic skin reaction, nose and throat discomfort and declines in serum cholinesterase levels. While the serious health problem can be damage in liver, kidney and central nervous system, loss of coordination and nausea in addition to cancer. According to the International Agency for Research on Cancer (IARC), some VOCs are put in group 1 as carcinogenic for humans like Benzene, Butadiene and Vinyl chloride. Asbestos is a sample of VOC s which is a group of six different fibrous minerals and it's commonly used for military service, shipbuilding, construction and heavy industry, since it is resistant to heat and corrosion. Asbestos is considered the main cause of many disease- although the symptoms may take long time to appear like 10 years or more- such as lung cancer, asbestosis, mesothelioma and pleural plaques. It has been known by another name which is the "**hidden killer**", although since 1970

the federal authorities have begun to regulate the use of asbestos products for the purpose to provide more protection for the employees, but it is still used because of its strong, cheap, resistance to electricity, water and chemicals, sound and heating installation. According to the- WHO, approximately 125 million employees are exposed to asbestos from their work while 50% of cancer death are caused by asbestos [15], [16].

Figure 3 illustrates the different sources of Volatile Organic Compounds (VOCs) for a typical modern household.



Figure 3: Sources of VOCs inside a modern household.

1.2. 3 Environmental Tobacco Smoke (ETS):

The negative outcomes from ETS reach a large number of citizens in developed and developing countries, and it is known as the largest modern source of indoor air pollution. In 2000, there was an estimation about 4% of global burden diseases is due to tobacco smoke.

Tobacco smoke not only harms the active smokers, but its negative consequences attack the people who inhale it and are called the second smokers and it has significant health risk factors in adults, children and infants, in addition to breast cancer and pulmonary tuberculosis.

In the USA about 3000 lung cancer deaths per year is credited to passive smoking, moreover and according to the US Center of Disease Control and Prevention (CDC) 400,000 per year and 50 billion USD medical cost from active smokers. Although being a passive smoker will have less direct health impact than being an active smoker but the best solution is by quitting smoking for all [17][18].

1.2. 4 Toxins in Nonstick pots and Pans

If a nonstick cookware is heated above 500⁰F, it releases toxic fumes. One of the chemicals that was used to make these pots and pans was PFOA, but these days it has been eliminated largely due to an agreement between major manufacturers and the EPA.

1.2. 5 Carpets

Release chemicals that are known as off- gassing, these gasses either from vinyl backing or the glue used to hold the carpet to the floor. Most of these chemicals take place in the first few months but little others continue releasing for five years after installing the carpet. It is classified as a known human carcinogen by the World Health Organization.

1.2. 6 Indoor inorganic contaminants:

Pollutants can be found anywhere inside and outside residences. But the difference is that inside we can find more inorganic gases because of the many indoor activities that take place and sometimes indoor pollutants can be 100 times higher than outdoor, we identify the main inorganic indoor contaminants as:

- Carbon dioxide (CO₂)
- Carbon monoxide (CO)
- Ozone (O₃)
- Sulfur dioxide (SO₂)
- Nitrogen dioxide (NO₂) and radon (it's an outdoor pollutants that sneaks to inside to be an indoor pollutants).

Carbon dioxide (CO₂) is a mixture of outdoor CO₂ with indoor breathing and the ventilation rate of the building. The lack of entering the fresh air into the residences and replacing it with air conditioners means that the percentage of CO₂ is high which will be an indicator of having poor indoor air quality. The increase rate of CO₂ will have negative effects on health such as fatigue, inability to concentrate, tachypnea (rapid breathing), headaches, dyspnea (shortness of breathing), flushing and dizziness in addition to blood pressure [7], [19].

Carbon monoxide (CO) is formed by the incomplete combustion of fuels. One of the main causes of having high rate of CO is burning fuel appliances and engines which produce carbon monoxide in closed spaces in addition to using clothes dryers, water heater, wood stoves, tobacco smoke and fire places. CO can't be smell or seen, if enter the body the CO molecules replace the oxygen in the bodies and lead to poisoning, the symptoms of CO are similar to that of flu and for this reason the patient delays to find the true cause of his illness and the treatment

becomes more difficult over time. Moreover, the symptoms of CO and CO₂ are similar but adding to them dull headache, vomiting, loss of consciousness and blurred vision. The time a person is exposed to carbon monoxide determines the side effects that provoke heart and permanent brain damage, fetal death or miscarriage and death. Urban babies, children, older adults and people who have chronic heart disease should avoid exposure to CO.

Nitrogen dioxide (NO₂) is resulted from burning fuel, like the use of gas stoves. Short exposure to NO₂ increase the incidence of respiratory diseases in particular Asthma and respiratory symptoms such as difficulty in breathing. As for the inhalation of nitrogen dioxide for a long time, it leads to the development of asthma and increase the respiratory infections such as lung infections.

Ozone layers (upper atmosphere like stratosphere) is a protection for human from the ultraviolet radiation emitted by the sun, but when the lower atmosphere reach the ground level and react with other certain pollutant such as volatile organic compound (VOCs) and nitrogen oxides that turn onto Ozone (O₃). Air cleaning products are one of the factors that cause high ozone levels in indoor air. This high level of O₃ can lead to a damage to people's lung and cardiovascular system, difficulty in breathing and development of respiratory disease in addition to asthma. Exposure to Ozone even for a short period but intense ivy increase the percentage of death.

Sulfur dioxide (SO₂) gases are emitted from burning fossil fuel. Inhaling SO₂, even for a short period, results difficulty in breathing, harm in respiratory system, moreover, children with Asthma will face a serious problems. Exposure to SO₂ for a long time may lead to a loss of smell, changes in lung function, decrease fertility in men and women in addition to bronchitis and shortness of breath.

Radon is a natural radioactive gas that enter homes, schools and work places through cracks and other holes in the foundation depending on the amount uranium in the underlying rocks and soils and the routs for the passage of radon from the soil into homes.it is the second leading cause of lung cancer after smoking in the USA, approximately 21000 people die from lung cancer related to radon. The average concentrations of radon inside homes or schools or offices -especially basement or first floor- is higher than outdoor radon level.

Particulate Matter (PM) is a mixture of solid and/or liquid particles suspended in air. According to EPA the smaller in diameter the PM the more dangerous 10 micrometers or less- this is due to the inbreathing of these small particles that enter the lungs or the heart and lead to serious problems. Outdoor PM have been subject to many studies and were used to adopt the health-based standards (NAAQS), while indoor PM is also found in all indoor environment and it can exceed the outdoor PM levels but still there is no enough data about its health impact. Many indoor activities lead to have high levels of PM inside houses such as cooking, chimneys, household products generating liquid aerosols, pets, and office equipment and construction materials of the house in addition to environmental tobacco smoke. Moreover, indoor PM can be found as a mixture of outside PM that infiltrate to inside with indoor particles.

Exposure to PM has many health effects starting from mild problems to serious or dangerous diseases, mild problems like shortness of breathing, cough and wheezing, chest discomfort and pain. More serious problems such as respiratory symptoms, decrease lung function, premature mortality which affects in a high percentage the people that suffer from heart and lung diseases, in addition to exacerbation of chronic respiratory and cardiovascular diseases. While exposure for a long time to PM may lead to other health problems like low birth weight in infants, fetal and infant deaths and pre-term delivers [20], [21].

It is the right of each human to breathe and drink clean air and water respectively or at least with acceptable quality. For this reason, the WHO Regional Office for Europe published in 1987 its first addition of Air Quality guidelines for Europe which included a whole chapter about indoor radon and an annex on tobacco smoke.

In 2000, WHO published its second edition of the guidelines focusing on the pollutants of the first edition, later in 2006 there were a global updating on a small group of pollutants such as Particulate matter, Ozone, nitrogen dioxide and sulfur dioxide in addition to a chapter about indoor air quality- since people spends of their times inside houses, schools or works- and its input on health in developing countries.

Indoor air quality (IAQ) is an important issue facing the governments and the environmental institutions. In Japan they started to solve a part of the IAQ's since 1990 by construction buildings with low ventilation rates in order to reduce such harmful problems. Also in Europe and America there were many programs put for the reduction of indoor air pollution [6].

Figure 4 describes the major effects of the indoor inorganic contaminants on health effect for an individual that we might be exposed to during his life in houses.

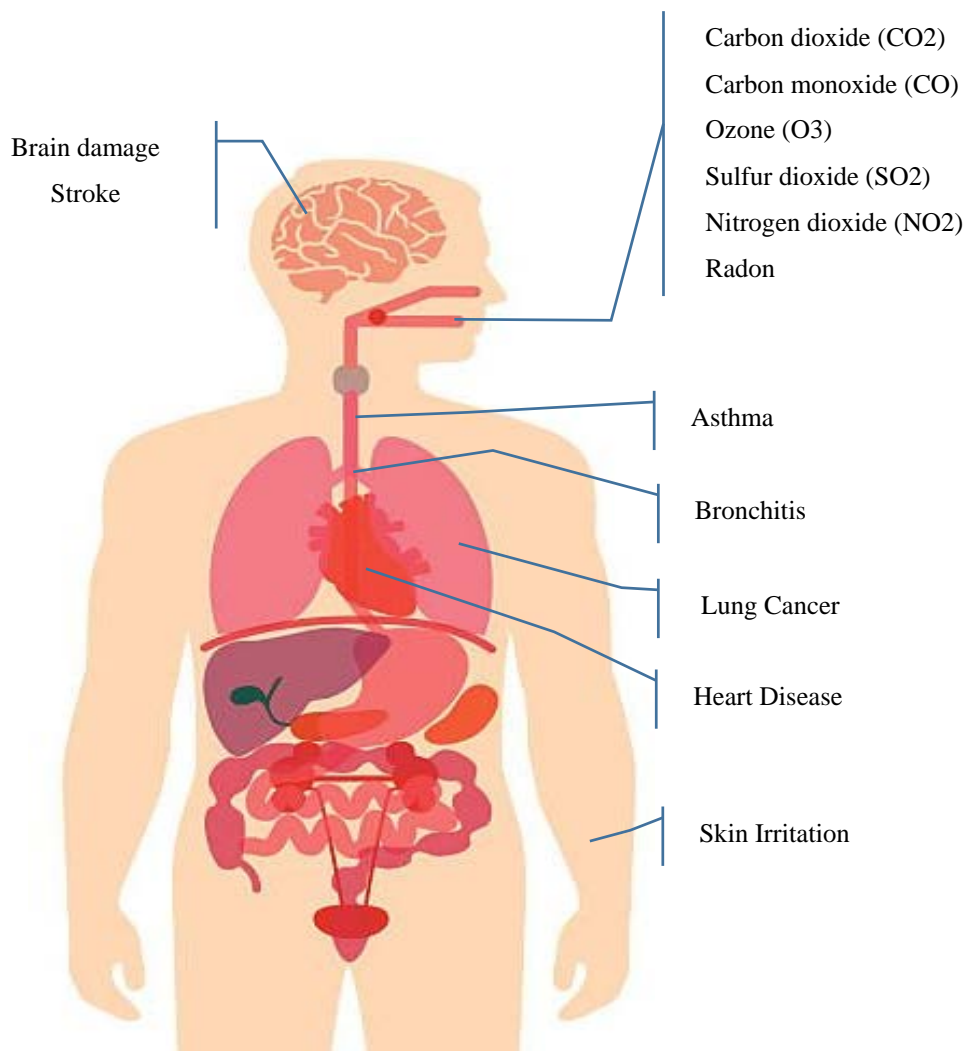


Figure 4: Effect of inorganic pollutants on human Health

1.3 Outdoor air pollution

Outdoor air pollution is defined as the presence or mixture of one or more substances in the air we breathe above the natural allowed limits mostly comes from the use and production of energy which are determinable to planet generally and human health specifically, it is classified as visible and invisible pollution.

According to the WHO at the end of 2016 the death's expectation due to outdoor air pollution was mainly related to heart diseases. Figure 5 illustrate the distribution of health concern as consequence of the outdoor air pollution.

Diseases related to outdoor pollution

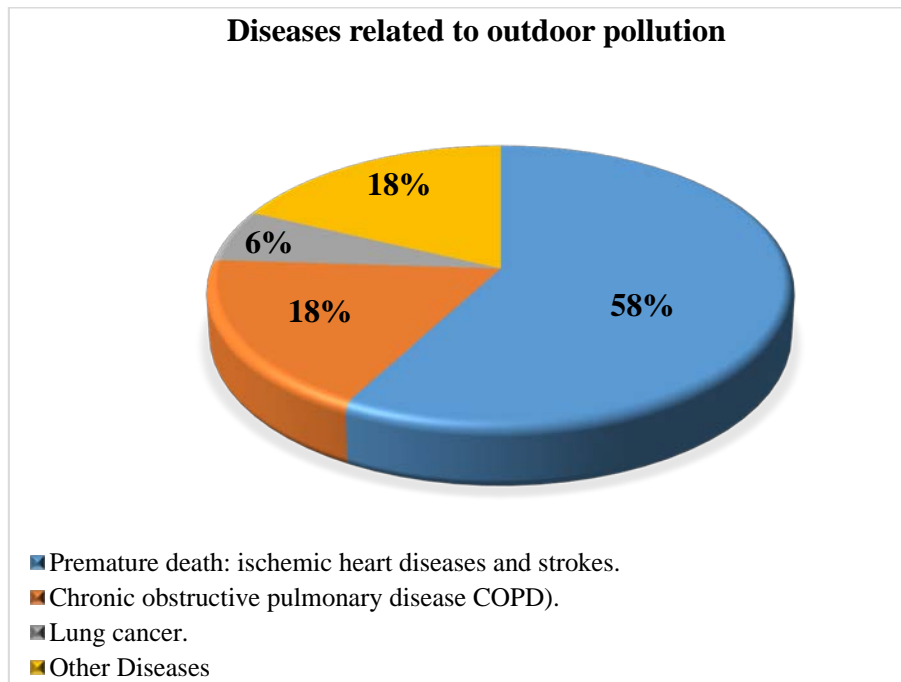


Figure 5: Percentage repartition of diseases caused by outdoor pollution

Where, premature death due to ischemic heart diseases and strokes share the highest value at 58%, followed by COPD with 18%, lung cancer 6% and 18% for other diseases (Asthma, fertility, etc...).

In terms of outdoor pollutants we can identify a five major pollutants sources:

- Ozone (O₃)
- Carbon monoxide (CO)
- Sulfur oxides (SO₂)
- Nitrogen dioxides (NO₂)
- Particulate matter (PM).

Outdoor air pollution is classified as “the great killer of our age” and its direct effects on health for all ages and genders. The five major pollutions sources (CO, SO₂, NO₂ and PM) almost have the same effects on health for the exposed individual at indoor and outdoor.

Ozone (O₃) is a gas composed of three atoms of oxygen and it may have either positive or negative effect, the non-harmful substance occurs naturally in the upper atmosphere and is called atmospheric ozone, and it protects the living beings from the damage of the sun’s ray. But with time passing and the increasing number of harmful activities induced by human that emit harmful chemicals substances to the environment the so called “hole in the ozone” occurred, scientifically named as troposphere or ground level ozone. There is an estimation that within year 2065 this hole will be fully recover but on the condition of domestic and international commitments towards the nature.

Tropospheric ozone is a chemical reaction between VOC and nitrogen oxides, this is due to pollutants emitted by cars, industrial boilers, chemical plants and power plants that react in the presence of sun. Outdoor workers, people that suffer from asthma, people with reduced intake of some nutrients like vitamin C and E, in addition to people with certain genetic characteristics are under big risk of ozone exposure. Inhalation of ozone can lead to serious health problems such as coughing, chest pain, and reduction in lung functioning and harm lung tissue [7], [19]. Societies that depend on private motorized transport, vehicles have bigger chance to be more safe, more powerful and driven more frequently, but on the opposite side there is no consideration for the increased fuel consumption and the increase in air pollution which lead to health problems.

In addition to that using more transportation means that society will have more traffic injuries, more noise and sedentary lifestyle. As a conclusion to these points we can say that urbanization made the problem of outdoor air pollution flows up especially in Asia, so there must be a solution to reduce the risks of health and meet the requirement of mobility. Solution may be achieved by putting number of policy initiatives. With respect to the WHO the first thing to be done is to analyses the scientific evidence on health risks and report the results to the governments and experts to reach the goal for protecting health. [22], [23]

According to a published study in 2012 by the World Health Organization, it has been reported that about 3 million deaths from outdoor air pollution and 6.5 million deaths were results from indoor and outdoor air pollution. Diseases like cancer, infertility, respiratory diseases and negative pregnancy outcomes are of direct link with air pollution. The highest percentage of deaths due to air pollution occurs in low- middle income countries, about 87% in West Pacific and South East Asian, China and India, where as the 13% rests occurs in high income countries like Europe, Americas, West Pacific and Eastern Mediterranean. The fast urbanization that is taking place especially in Asia is making the problems of air pollution more visible and having more health problems, one of the problems is city design if the city is crowded with height buildings and very close to each other's this means that the wind will not be able to enter and the air will not be spread everywhere.

It has been demonstrated that time exposure to air pollution play a role in the kind of diseases such as short- term exposure has related with cough, shortness of breath, asthma, respiratory diseases and high rate of hospitalization. While long- term exposure to air pollution leads to chronic asthma, pulmonary insufficiency, cardiovascular diseases and cardiovascular mortality. Increasing in air pollution means an increase in morbidity and mortality [7], [24].

Upon a study made by the WHO, million premature deaths every year due to air pollution, 14% of children between 5 and 18 years are suffering from asthma, approximately 543 000 children

younger than 5 years due to respiratory diseases in addition to childhood cancer. Heart failure also a major cause of air pollution where about 23 million people worldwide is suffering from, additional to lung cancer which is a cause of indoor and outdoor air pollution.

The use and production of energy is one of the most causes of air pollution since it releases gases and chemicals into the air like fossil fuel which is a major contributor to air pollution, moreover, air pollution is linked to climate change and this climate change affect negatively the basic elements in our health, air, water, food, that is why there must be an actions taken quickly. [20], [24]

Sometimes the air pollution can be seen by eyes like cloud called “smog”, this word is a combination of two words “smoke” and “fog”.

Having outdoor air pollution is not only because of Man- made but also from natural sources such as emission of methane after the digestion of cattle, emission from wildfire, radioactive decay and the sulfur and chlorine deposit after the volcanic eruption but these reasons have a very low percentage in affecting the air quality.

Air pollution is a very serious and dangerous problem facing developing countries since most of the studies that have been done recently highlighted the direct relation between air pollution and health risk which is called sick building syndrome (SBS). And here we are talking about both kind pollutants indoor and outdoor air pollutions in addition to many studies that have confirmed the direct affection between outdoor and indoor air pollution. [9], [25]

From the above we can conclude that there are two types of pollutants:

- **Primarily air pollutants** that are results directly from the process, such as the sulfur-dioxide emitted from factories.
- **Secondary air pollutants** that are caused by the inter mingling and reactions of primary pollutants such as the smog created by the interactions of several primary pollutants.

Below we give in details the main causes of air pollution [6], [22], [26], [27]:

1.3. 1 Agricultural activities

Use of fertilizers, pesticides and insecticides in agricultural activities has increase recently which leads to have harmful chemicals in the air and also cause water pollution this is called Ammonia. It is much known in the production of agriculture activities and it effects the atmosphere by hazardous gases.

1.3. 2 Mining operations

Extracting minerals from the earth need large equipment, these kind of activities leads to spread dust and chemicals in the air and the main patience are the workers and nearby residence.

1.3. 3 Exhaust from factories and industries

Manufacturing industries can be found at every corner of the earth and there is no area that has been affected by it. It release large amount of carbon monoxide, organic compounds and chemicals into the air which affect the quality of the air.

1.3. 4 Burning of fossil Fuels

Burning fossil fuel like coal, oil and natural gases provide about 80% of the total energy needed for transportation, heat and electricity. On parallel to this need, the percentage of global warming is increasing by releasing large amount of carbon dioxide, sulfur dioxide and particulate matter.

Therefore, it can be said that the fuel bill is paid twice, the first bill is the cash payment to obtain the fuel while the second bill is paid from human health and environment.

Our basic needs of transportation which is vehicles such as trucks, jeeps, cars trains and airplanes cause pollution. In Urban areas 30% of fine PM (particulate matter) from road transport is emitted from Tailpipe. Road transport is the first reason for having a flow off nitrogen dioxide and benzene in cities and it plays a main role in non- compliance with current European Union for decreasing these pollutants.

Streets with heavy traffic and the overuse of vehicles have a higher percentage of nitrogen dioxide, black smoke and ultra-fine particles then streets with low traffic in addition to killing the environment as dangerous gases. Another issue which causes air pollution is the Sulfur dioxide that is emitted from the combustion of fossil fuel like coal, petroleum and other factory combustibles.

In figure 6 a summary representation for the many adverse health effects caused by the outdoor air pollution.

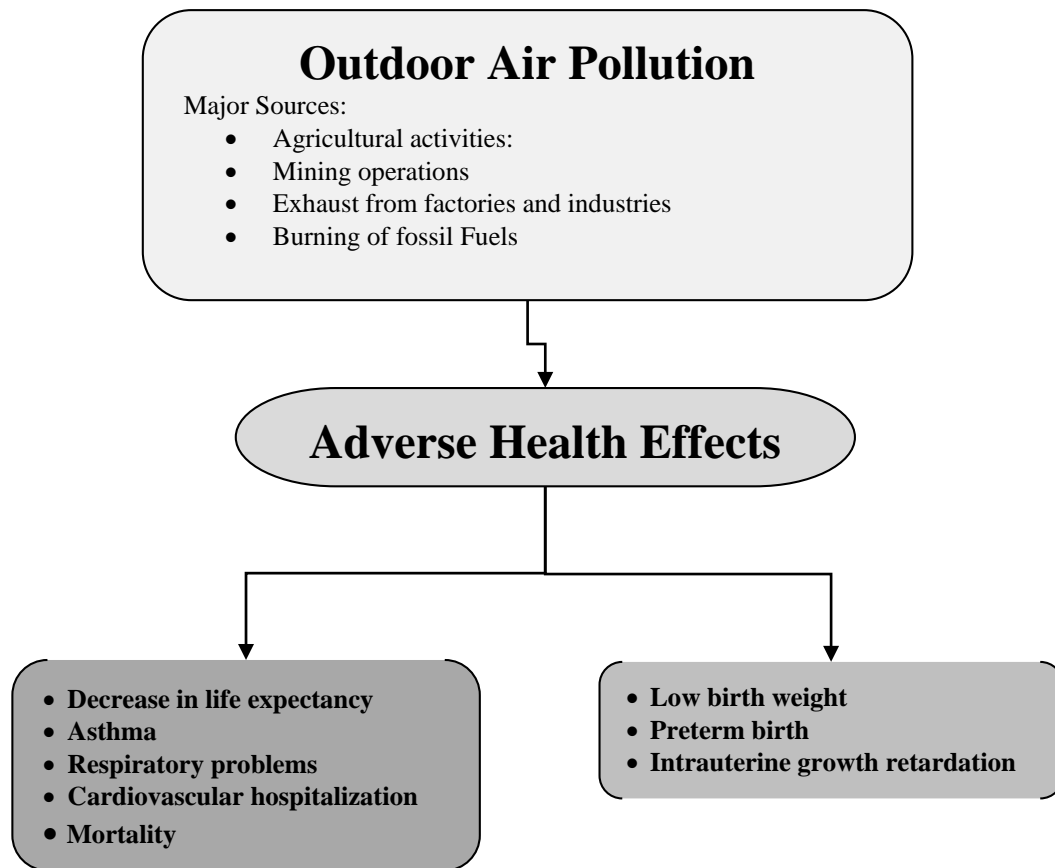


Figure 6: Summary for the adverse health effects caused by the outdoor air pollution.

1. 4 Impact of Particulate Matter on Health

Air pollution is a combination of gasses, particulates and biological molecules. Gases such as ammonia, carbon monoxide, sulfur dioxide, nitrous oxides, methane and chlorofluorocarbons. Molecules or sometimes called biomolecule include large number of macromolecules such as protein, nucleic acids, carbohydrates and lipids, also small molecules such as small products. Particulates is a mixture of many components like acids, organic chemicals, metals and soil or dust particles. The size of these particles play the main role with respect to health risk, and it is categorized under the diameter PM10, PM 2.5 and PM0.1. PM10 means particulate matter below 10 um in diameter and known as thoracic particles, when we inhale PM10 it landed in proximal airways. PM2.5 means particulates matter below 2.5um in diameter which is known as fine particles and it causes the greatest risk to health since the particles are very small and can reach the lungs and stick in the alveoli. PM0.1 means particles with a diameter <0.1 um and known as Ultrafine particles (UFPs).

The smaller the particles the more dangerous to health like the PM2.5 and PM0.1 that can reach the lungs and the brain through blood stream. PM have a direct impact on the average life expectancy, with respect to Europe and according to the WHO in 2009, there is a variety

of life expectancy between Western part of Europe and the Nordic countries from one side and have many years longer than the Central and Eastern Europe in the other side due to air pollution from PM which leads to a loss of 725 000 years annually. Expectancy among 27 countries in European Union was of the highest in the world approximately 76 years for men and 82 years for women [6], [28], [29].

An increase of $1\mu\text{g}/\text{m}^3$ of $\text{PM}_{2.5}$ for 1 year equivalent to a loss of 0.22 days per person. Moreover, exposure to PM ($\text{PM}_{2.5}$) causes approximately 348 000 annually perimeter deaths in EU countries. Of course, long-term exposure to fine particles matter have higher risk effects on health than short-term exposure regardless age, gender and geographic region. This long – term exposure to PM 2.5 increases the risk of non-accidental mortality from lung cancer and total cardiovascular mortality by 6% for each $10\mu\text{m}/\text{m}^3$.

As a human we are effected by everything surrounding us mainly the environment we live in and the air we breathe. The polluted air we inhale will harm the human health particularly old people, people with pre-existing conditions such as heart disease, high cholesterol and high blood pressure or children that have health problems, without forgetting the time exposure to air pollution. Long- term exposure will not have the same causes as short-term exposure. Citizens living in a city with high level of pollution and for a long period will have a higher risk of hospitalization and early deaths than those who live in less polluted area [30].

Asthma, Respiratory and Cardiovascular hospitalization, changes in lung functions and mortality represent some causes of air pollution. Recent study in Europe showed that exposure to particulate matter (PM) lead to a loss of 8.6 months of life. PM is one of the most dangerous pollutants and have direct impact on mortality, approximately 500,000 deaths per year among 40 European countries.

With respect to children living in a polluted area and exposure to PM will suffer from chronic disease such as asthma or incidence of respiratory systems, moreover they have lower intelligence quotient(IQ) (mothers that have smoked during pregnancy will cause a negative effect in the children's IQ) then children living in clean area.

Asthma is the most commonly disease among children and it is not any more related or restricted to a specific seasons or environments, it represents a major causes of hospitalization for children under 15 years old. Half of the global death occurs from cardiovascular disease which is caused mainly from fine particulate[7], [23], [25].

Having an increase among six years of $10\text{mg}/\text{m}^3$ of PM will have an increase in mortality between 6.8-13.2%. Moreover, an increase of $10\mu\text{g}/\text{m}^3$ of PM 2.5 over 2 years will increase

the risk of death by 22% for people with inflammatory, 28% for COPD patient, 27% for congestive heart patient and 32% for diabetes patient. Cardiovascular disease is the guiding cause of death among the world and of direct relation of airborne particles and sulfur dioxide. The most dangerous PM those that are produced by automobile exhaust or from smoking, these particles cause damage in arteries in the heart and brain. So an inflaming in the level of PM will higher the risk of cardiovascular disease and death in post- menopausal women.

Many researches from time ago had observed the negative effects of air pollution on pregnancy outcomes and infants. Pregnant women living in areas with high level of air pollution especially from motor vehicles or heavy traffic roadways for a long time will have an increase of 20% of having a low birth weight (this may lead in the future to have type 2 diabetes, developing in adulthood coronary health diseases and hypertension), preterm birth (birth that takes place before 3 weeks or more than the estimated date) and intrauterine growth retardation (unborn baby but smaller than showed be because it is not growing at a normal rate inside the womb). These three problems facing the pregnant have an interrelation with infant mortality and morbidity[27].

Nowadays pollution is considered one of the major or important topic facing the humanity, although we had an industrial revolution which had considered a great step in all directions such as technology and society but this revolution had increase the pollution such as Urbanization and industrialization, in other words the activities we do are the major pollutants for the environment we live in.

In developing countries the problem of urbanization and industrialization is more serious since the society in such countries don't have enough information about how to protect their environment and because of the low income, citizens still use the traditional ways in their heating and cooking which is considered a very dangerous and harmful pollutant of indoor air pollution (about 3 billion people are using these traditional ways). Women and children are mostly affected by indoor air pollution since they spend most of their time inside the house[31]. Figure 7 gives a detailed description concerning the possible inhaled Particulates Matters and their harmful effects on human's body depending from their sizes

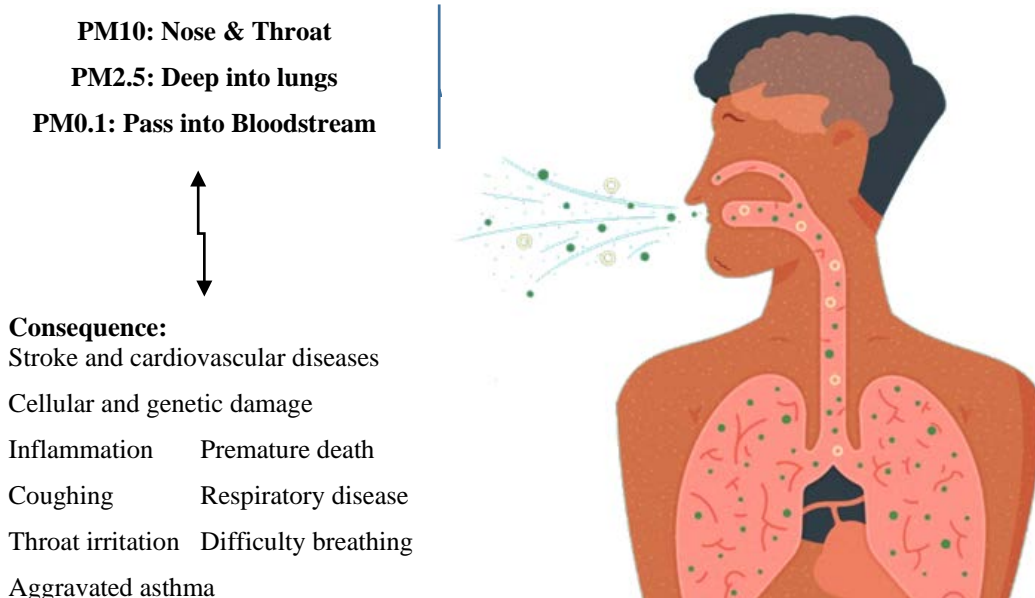


Figure 7: Inhaled Particulates Matters by different sizes and resultant harmful effects on human's body

1. 5 Impact of air pollution on the Economic

Besides causing many damages on health, air pollution has negative effects on economic especially in middle – low income countries. There are many steps that we have to go through in order to calculate the consequences of outdoor air pollution, but before we have to know that the total cost of inaction of outdoor air pollution is divided in two categories market and non-market cost. The market costs are those that associated with biophysical impacts such as health expenditures, labor productivity and agricultural yields and it is of direct and indirect market cost - a decrease in crop yields will lead to a direct impact on agricultural output of the affected crops, but also to indirect effects, including substitution by other crops and changes in trade patterns- non- market cost are related to cost of mortality like premature death and disability of illness[22][32].

Premature death is considered as a weighted factor on the development of the economy in any country and is directly related to the air pollution especially in the countries with fast growing economies like China and India where those countries are experiencing a rapid increase in the industrialization causing air pollutions. A global projection highlighted that the number of premature death will increase in China and India from 3 million in 2010 to 6 or 9 million in 2060.

For the countries consortium in the Organization for Economic Co-operation and Development (OECD) the projection number was approximately 430,000 and will reach 570,000 to 580,000

in 2060 mostly in Japan and Korea. The premature death is a real lost in the economic cost of a society and this lost was reported by the OECD in 2010 for the 34 OECD counties plus China and India for about \$3.5 trillion [3], [11].

Chronic diseases are also considered as an economical cost of air pollution, e.g. more hospital admissions, medical treatments and health expenditures which also leads to having more sick days and this equivalent to labor productivity losses. These diseases are distributed among cases of bronchitis and asthma between children and Citizens suffers from chronic obstructive pulmonary disease (COPD), stroke and Respiratory infection and diabetes. The approximately lost working days in 2060 is expected to be 3.75 billion days.

Increasing the percentage of having asthma attacks and sickness days will have a negative results on schools (children disease) and of course increase in the costs of health care which also will lead their parents to take off from their works. Each year about 4 million new cases of asthma among children, while 16 million children all over the world live with asthma, and these results from the exposure to NO₂ [33].

High level of air pollution will reduce the agricultural production such as the wheat and seeds that are affected more than the other corps and this can be also considered as an economical loss.

In 2018, an estimation of 3 million deaths are caused by PM_{2.5} pollution, 990,000 deaths from ozone and 500,000 from NO₂ pollution, as a conclusion 4.5 million people died from exposure to air pollution from fossil fuel with a loss of 19 years of life/death. In figure 8 a summary for the main negative impact of the outdoor air pollution air pollution on the economy.

Increasing the percentage of having asthma attacks and sickness days will have a negative results on schools (children disease) and of course increase in the costs of health care which also will lead their parents to take off from their works. Each year about 4 million new cases of asthma among children, while 16 million children all over the world live with asthma, and these results from the exposure to NO₂ [7], [11], [23].

We can't forget the pregnant women that are exposure to air pollution especially PM_{2.5} and the high risk of having preterm birth and the premature deaths. With respect to WHO and OECD, the economical cot of premature death and disability from air pollution is approximately 1.6 trillion in Europe. After all these health cases, there are 1.8 billion days of work absence, from this we can notice the reduction of labor participation and decrease in labor productivity in addition to increase imposed in the cost of health system. In 2018, 2.9 trillion USD was the estimated economic costs from the health sectors or 3.3% of global GDP. Countries with high percent of air pollution will have a higher economic costs on deaths and chronic diseases[11], [22].

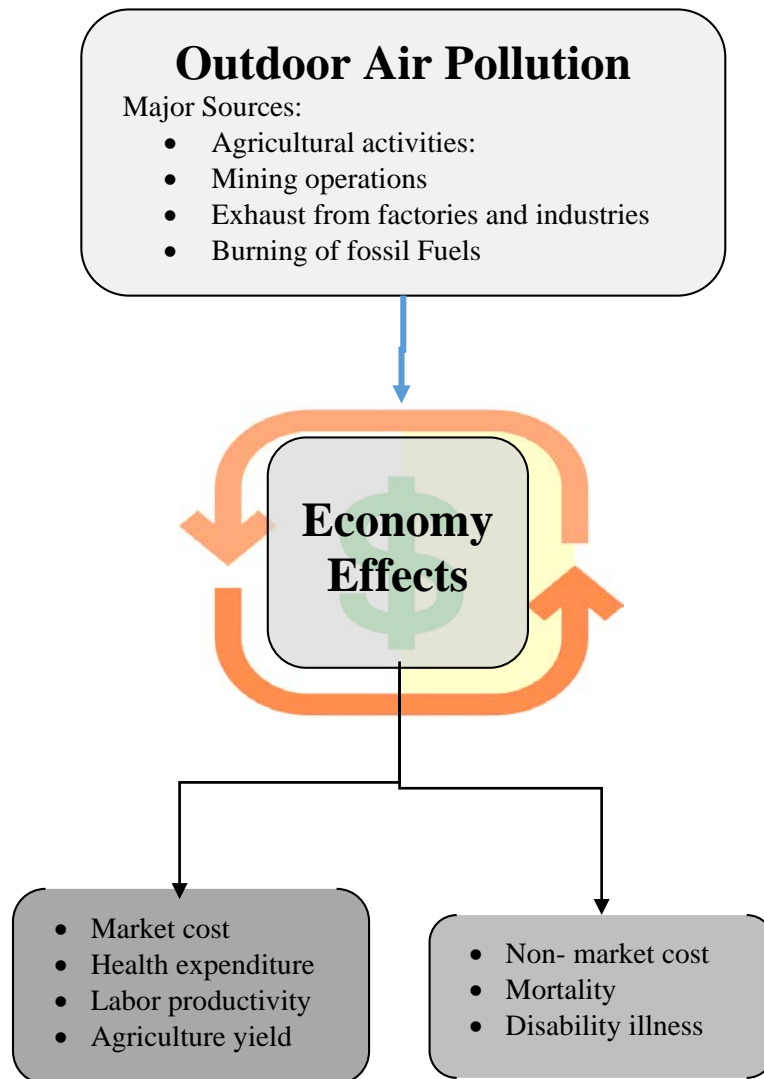


Figure 8: Summary for the impact of the outdoor air pollution on economy

1. 6 INTERNATIONAL AGREEMENTS AND PROTOCOLS

Adhering to a specific protocol maybe one of the solutions for the reduction of Green House Gases (GHG) for all nations in developed and developing countries. Kyoto Protocol and others that were adopted to help countries in the reduction of gas emissions are considered an ultimate solution to slow down the emissions and their consequences.

1.6. 1 Kyoto Protocol:

The aim of this protocol is to reduce the emission of greenhouse gas primarily carbon emission worldwide. It was adopted and delivered in Kyoto, a Japanese city and that is why they called it Kyoto protocol. This protocol is an agreement established by the United Nation in 1997. The scientific comity among the UN believed that global warming is a real phenomenon due to human activities.

Kyoto protocol didn't enter into force until February 2005, it focused on the reduction of GHG emissions for 37 developed nations as being the primary sources of carbon emissions while developing countries could comply voluntarily. The Kyoto system was "carbon credits system" whereby nations can credits by participating in emission reduction projects in other nations. There is no unified system or law, on the contrary, every party adopts the policies and measures to follow and submit report periodically[34], [35].

Over time, the beliefs of the UN appeared to be flawed regarding emissions from less developed or developing nations which register more carbon emissions worldwide. For example in 2020, China and India recorded about 35% of total carbon emissions because they rely on coal as an energy source while the developed nations like UK, France and Germany accounted for 4% of the total carbon emissions.

Although this protocol was extended to 2020 in Doha Amendment in 2015 but it became a debating point after most of its original ratifies signed the Paris Climate Accord, where the U.S withdrew from this agreement later on. Currently, there are 192 parties to the Kyoto Protocol.[34].

1.6. 2 Paris Agreement:

Also known as Paris Climate Accord, the goal of this agreement is to limit global warming less than 2 if possible to 1.5 degree Celsius above the industrial levels by the year 2100. It was approved by 196 parties at COP21- Conference of Parties to the UN Framework Convention on Climate Change (UNFCCC) this is another name for the agreement- in Paris on 12 December 2015 and enter into force on 4 November 2016, Syria was the last country who signed the agreement while Iraq, Iran and Turkey still didn't formally enter the agreement although they suffer from gas emissions. The United States left the agreement in November 2020 because the president Trump was convinced that the Paris Accord would affect the domestic economy negatively although U.S has an approximate global gas emission of 15%, but in January 2021, President Biden announced that U.S will rejoin Paris agreement[36].

The Paris Agreement is a legally binding international treaty on climate change, it was the first agreement to bring all nations together around one point which is combating climate change and adopt to its effects. This agreement works on a cycle of 5 years where countries submit their plans for climate action known as nationally determined contributions (NDCs). In this NDCs, nations converse the action they will take for reducing their GHG emissions and how to build resilience to adopt to the impacts of rising temperatures.

Paris Agreement asked the countries to map out and submit long-term greenhouse gas emission development strategies by 2020 in order to frame the efforts done. Providing the strategy to the

NDCs is not obligatory but it give the NDCs a scheme about the direction of future development of the countries. Another strong point for this agreement is the supervision of developed nations to less endowed countries, moreover, these developed countries provide each year \$100 billion for the developing countries since not all these countries have the building capacity to deal with such challenges regarding the climate change and the amount will increase over time when this agreement becomes effective [37], [38].

1. 7 Pollution in Lebanon

Lebanon is considered as an advanced country in some sectors like Banking, Medicines and education system particularly at the universities level, but despite all the achieved progress the country still facing a serious and very dangerous problems in terms of ecosystem such as pollution, environment respect, Industrial residues and many others.

Existing Problems related to the environmental protection, pollutions, and their consequence on the society, was completely ignored for many decades by the concerned authorities and never has been proposed the right and sustainable solution. [39], [40].

In 2013, the Word Bank and Institute for Health Metrics and Evaluations of the University of Washington published a research about Lebanon's air pollution problem. The researchers in this study depended on PM_{2.5} (which is a very fine particulate matter that has a diameter less than 2.5 micrometers and cause health problems moreover it lance deep inside the lungs causing many diseases. PM 2.5 is released into the atmosphere combustion sources) [40].

The WHO put the guideline for the PM 2.5 as 10 $\mu\text{g}/\text{m}^3$ (annual) and PM₁₀ as 20 $\mu\text{g}/\text{m}^3$, where Lebanon has higher level of PM 2.5, in 1990 the level of the PM 2.5 were 24.39 $\mu\text{g}/\text{m}^3$ and in 2013 the level of the PM 2.5 were 23.56 $\mu\text{g}/\text{m}^3$ more over there is no legal limit in Lebanon for PM_{2.5}, not just Lebanon 87% of the countries exceeds the guideline of the PM 2.5 [39], [41]

From the above mentioned studies there was an estimation for the number of deaths in Lebanon caused by air pollution, where in 1990 around 1,160 and in 2013 the number increased to 1,816 deaths. According to Greenpeace, Lebanon has the highest pollution link death rate in the Middle East. In 2018, the estimated numbers of deaths caused by fossil fuel was 2 700 which is a rate of 4 deaths/ 10 000 people and exceeds the Egyptian rate that was 3 deaths/ 10 000 people, also the premature death in Lebanon is the highest among Syria and Egypt [14], [40].

The percentage of pollution per type polluted category in Lebanon is given in figure 9, where polluted percentage of the water reached 78 % followed by the Air at 76%, drinking water when it is available at 69%. A level of pollution that can be considered from the highest in the world with direct harmful effect on the public health.

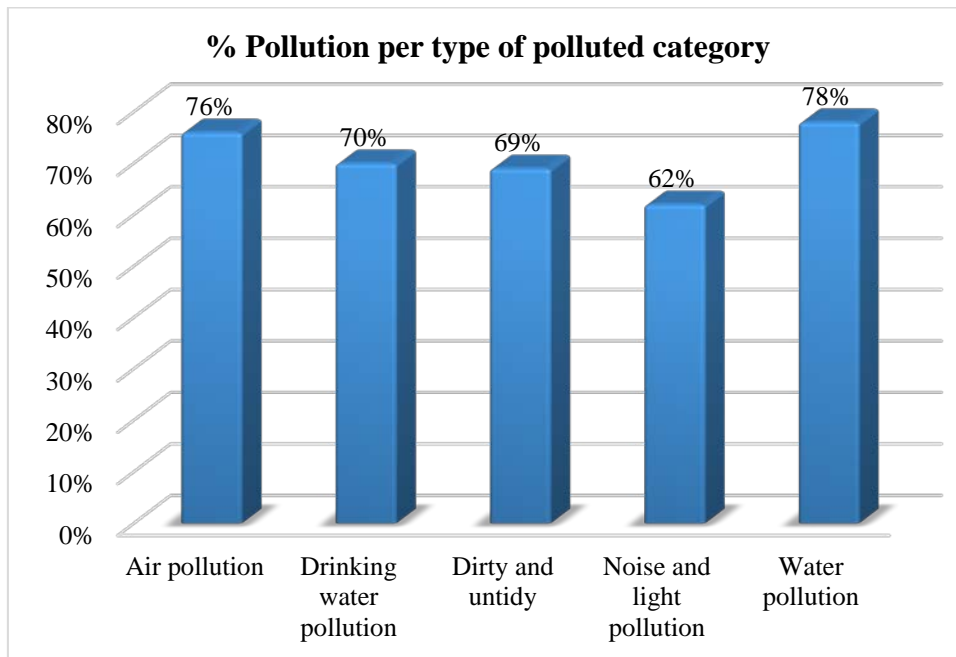


Figure 9: Pollution percentage for Air, Dirty and untidy, Noise and water in Lebanon

1.7. 1 Sources of air pollution in Lebanon

The primary source of air pollution in Lebanon is attributed to the sectors of transportation, energy, industrial and construction. The main contribution of CO₂ emission is the energy production, 40% of the total emissions, which are mainly thermal power plants. The industry is responsible for the inflexible black plumes that plague Beirut and emit multitude of pollutants such as hydrocarbons, carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen oxides, soot, and particulate matter. The bulk of the factories don't use the necessary equipment to reduce pollution emissions such as flue gas desulfurization, scrubbers, filters, and dust collection units. Al- Zawq thermal power plant, figure 10, is an example of the biggest problem in Lebanon related to air pollution and affecting the health of people living in the area, yet no action or even one of the promises given was proved on the ground.[42]



Figure 10: Thermal power plant in Lebanon (Al- Zawq)

Our Lady of Lebanon Hospital in Jounieh noted during the year 2014, 1,300 cases of asthma attacks and 1,200 cases of acute respiratory infections, in addition to 84 cases of lung cancer and all these cases related to the thermal power plant [39], [43]. Those thermal power plants are the most prevalent producers of CO₂ emissions, involving 39% of the total carbon dioxide emissions in Lebanon in 2005.

In addition to the above cited causes of pollution we emphasize a major cause of pollution in Beirut, the capital city of Lebanon, the transportation pollution. Actually there is an estimation number of approximately 5 million vehicles registered (public and private) and circulation in the city that has a very small area.

- ***Transportation sector:***

Till the edition of this thesis no one of the public authorities have taken any step forward to improve the public transportation dramatic situation in Lebanon. Moreover, some measurements were done by the governments by supporting private credits to purchase cars and mini-buses which led to an unprecedented rise in vehicles imports. Over the period of 1997-2007 the number of vehicles in the country have doubled where in 2009 the total number reached 100 000 vehicles, figure 11, a number considered as immense with respect to a small country like Lebanon.

The weakness of the public transportation has led to an increase in the number of private cars and most of these cars are not subject to the international specifications and are old cars. The majority of Lebanese vehicles operate on gasoline and 67% of non- methane VOC emissions are related to transport, on the other hand the old cars have higher emission percentage of CO₂ and this is what we are facing, to put the first stone for solving this issue is by revitalizing the public transportation and put restricted laws on the imported cars with higher taxes on old cars.[3], [8]

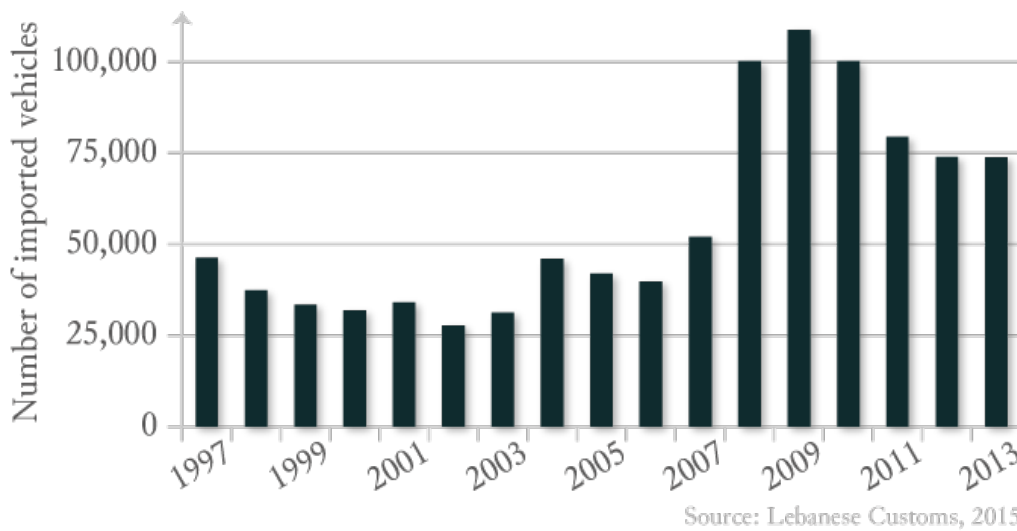


Figure 11: Imported vehicles in Lebanon for the period 1997–2013(data provided by Lebanese Customs 2015)

- **Wastes sources:**

There are two ways to get rid of wastes in Lebanon, either by classical thermal treatment (burning) or landfilling, figure 12 and 13, where the two methods lead to a severe bad consequence on the environment and in particular in the air pollution.

Burning the wastes produces a Toxic gases such as carbon monoxide and dioxide, where the damage effect of CO and CO₂ on human health has been scientifically demonstrated by a very solid published papers. Another toxic gas is the dioxin which can affect the nerves and immune system leading to many number of cancers. The second way employed in Lebanon for waste treatment is the landfills, al-na'imah landfills is the biggest dump in Lebanon, where it was closed because of serious health problems among living residents in the nearby area. [3], [8], [44].



Figure 12: Classical Thermal treatment for waste in Lebanon (© 2017 Reuters)



Figure 13: Al-na'imah landfills is the biggest dump in Lebanon (@envjustice, 2019)

Also it was observed that it is very difficult to define in Lebanon the exact ratio of air pollution or to measure the amount of produced toxic gases due to many uncontrolled sources of emissions. A statement was issued by the Lebanese National Council for Scientific Research express clearly that pollution increased more and more rapidly with a level exceeding the average rates by nearly 120-fold in particles with diameters less than 10 micrometers, whereas air pollution in particles with a diameter of 2.5 micrometers per particle exceeded the average rates by six- fold.

Additional problem has been accumulated to the existing environmental problem is the sudden increases of the population concentration in Lebanon coming from the refugee, where it has been noticed that solid waste production was increase by a value of 15 per cent after the

immigration crisis, while the air pollution was augmented by 20 per cent and the wastewater by 14 per cent. All the previous values show the level of the environmental crisis and its fall back on the Lebanese ecosystem.[45]

- ***Electricity sector:***

The lack of electricity supplied by the government and the consistent number of hours with current rupture has forced the citizen to use Diesel generators either at personal level or by subscription from commercial private suppliers. In Beirut city and surrounding area we can notice that almost there is at least one generator per quarter, moreover, there is no accurate data about the emissions coming from these Diesel generators on daily or weekly basis. The only available data is taken from a study realized every three years which is not enough at all to know where we stand with respect to the international norms.

Replacing these generators by sustainable source like smart grids combining solar and wind energies is the ultimate solution toward an improvement in the air quality and environment protection.[46], [47]

Domestic waste is considered as one of the major problems that we are facing in the country, where these garbage are not sorted neither from the starting point at home nor by companies or factories supposed to treat them. In reality this kind of misconduct aggravate the problem and make it much more complicated for solving because sorting the wastes after combination become very difficult to achieve the recycling phase. So far and after many consulting at national and international levels, it was advised that the only accurate solution is by starting sorting the wastes from the household and with many selections (Plastic, papers, bio, etc...) that will have many positive fall back on the health, environment and economic level.

According to the WHO, 100% of the Lebanese population are exposed to pollution level that exceeds the standard guidelines. In 2019, Lebanon was rated the 5th among 91 countries with respect to the level of outdoor air pollution, especially in Beirut which is considered a densely populated urban area. Between 1082 cities in the world, Beirut was ranked in the 176th level of outdoor air pollution also.[42]

- ***Beirut Explosion:***

On the 5th of August 2020 a massive explosion occurred in the port of Beirut, figure 14, that was compared to Hiroshima Atomic Bomb in terms of explosion force and resultant damage on the Citizens, economy and environment. The weight of the explosive materials (Ammonium nitrate) was estimated to 2750 Tons, where neighbor countries, Cyprus and Some Greek Islands, heard and felt the sound of this explosion [48].



Figure 14: ammonium nitrate explosion in August 04, 2020, in Beirut City

Beirut residents lost their homes (300 000 people homeless), jobs and about 200 people died and 5000 injured, the material losses were estimated by \$15 billion. A plume of orange smoke soared in the sky and a big pressure shook the buildings and damage the glass of the city, all who lived in Beirut could see a massive pollution covering the capital.

Up to this point, there is no data available about what actually exploded besides ammonium nitrate, so there is no ability to know how toxic the dust is, in other words what is the kind of pollution, level of pollution or the potential impact, this is according to the Greenpeace's Middle East and North Africa program manager in Beirut.

Note that when ammonium nitrate is heated, toxic gases released like nitrogen oxides (NO_x) and ammonia gas (NH₃) in addition to that when these gases react with other chemicals they will be more harmful to the human respiratory system and the environment. For example, when Nitrogen oxides combined with other pollutants and sunlight form "bad ozone".

Before the explosion, Beirut had already exceeded the norms of the WHO with respect to PM_{2.5} by 30 micrograms per cubic meter and now without any new up dated information, the Lebanese don't know at which level of pollution they stand.

This bad scenario of environmental degradation is repeated several times in Lebanon, either by the released pollution from Diesel Generators or by the waste crisis that filled Beirut's roads, spread the unpleasant odors and pollutant gas emissions where till the date of thesis editing the government is not able to find any solution for all these issues [49][50].

1. 8 CONCLUSION

In this chapter, we have discussed the causes of Indoor and Outdoor air pollution with their negative impact on public health and economy, where citizens are paying the highest bill of these pollutions. Also it has been observed that impact of air pollution in developing countries is higher than that in developed countries due to intensive use of traditional technics in most of their life's activities, inside and outside houses, like biomass energy production for living or electricity generation obtained from classical burning fossil fuel.

It has been shown that traffic, diesel generators and wastes are the main sources of air pollution in Lebanon, studied case in this Manuscript, where values are very alerting and there is an urgent need to apply sustainable solutions for decreasing the percentage of air pollution and to avoid the ultimate disasters that may results from the actual practice.

CHAPTER 2: ENERGY DEMAND, AVAILABLE RESOURCES AND MICROGRIDS SOLUTION FOR LEBANON

Abstract

In chapter 2 we have focused on energy demand and the main causes of energy shortage in the developing countries. During our study we have concluded that energy deficiency is mainly related to the lack of political plans of government, population growth, tangible resources and increase in the consumptions during the last 2 decades.

Recently many countries, including those that export large quantities of petroleum realized that these resources are depleted and in order to avoid the possible deficiency in the future, they started investing in Renewable Energy.

Concerning Lebanon, our case study, investing in Renewable Energy can be of high interest for the economic and social prosperity that may solve pollutions' problem resulted from the excessive use of fuel energy in this country.

2. 1 Introduction

International communities have always focused on finding solutions for global problems related to environmental pollution and climate change in developed and developing countries, where those issues are the most important faced challenges.

In 2009, a study has been conducted by the United Nations about the main four causes of having a lack in energy supply in the developing countries, which are:

- Lack of political plans for governments.
- Population growth.
- Tangible resources.
- Load growth.

The demand of energy is continuously increasing worldwide since the industrial revolution. Middle East (ME) countries exports large quantities of petroleum to world countries, but in the last decades they have realized the real fact of these resources depletions and we start to notify an investment in renewable energy sources especially in the GOLF region. Recently, most of the world countries are putting a road map for renewable energy implementations. In the

European Union (EU), the range of installed wind turbine and PV have soared from 2.5 GW in 1990 to 115 GW in 2010 and 218 GW in 2014 lead to an increase in the generation of electricity from renewable sources from 12.6% in 1990 to 29% in 2014.

As for Lebanon, it is a country that imports 98% of its energy requirement where investing in Renewable Energy Technology (RET) can be of high interest for the economic and social prosperity, especially that Lebanese society is facing many difficulties from the high level of pollution resultant from the fuel energy use.

Electricity in Lebanon comes from two main sources:

- Electricité du Liban, EDL (Public Sector)
- Diesel generators (private sector)

EDL is operating at 95% with Fuel oil and the private diesel generators run completely with diesel, where both are a consistent source of air pollution in the country. Thus the necessity of integration renewable resources to reduce the pollution emissions.

2. 2 Energy sources, needs and availabilities

The growth in energy demand since the industrial revolution lead to more challenges to ensure their demands with low-carbon emissions. Developed countries are the highest in energy consumption like Canada, United States and some countries in the Middle East like United Arab Emirates, Qatar and Oman where they are considered. For under-development countries the existing data about energy consumption is not enough for making comparison since they still rely on traditional ways of energy production such as biomass, wood and other organic matters.

The humans' global energy consumption from renewable energy was 16% in 2011 and 19.2% in 2015, where 23.7% of them goes for electricity generation annually. The advantages of these renewable sources are the ability of producing energy without or with little emissions which have little environmental impact.

To encourage more investments in renewable energy production and to limit emissions, the European Parliament, the Spring European Council and the European Commission have put many policies and rules for fuel consumption supply.

Renewable energy is expected to supply more than half of the global electricity production in the world by the year 2035. In 2016, Germany, China, Japan, Italy, United States, France, Spain, UK, Australia, Belgium, Thailand, Netherlands and Switzerland are the top countries that produced energy from renewable sources. Renewable energy reduces the fuel consumption in four areas which are electricity generation, hot water, motor fuels and rural energy services.

2. 3 Micro grid: Concept, Utility and Function

Micro grid is a small power grid for either distributing, decentralizing or embedding energy production, where it can operate independently or with several small networks called grid. One of the advantages of micro grid is that they can be located near the energy consumption like college campus, business center for providing electricity, heating and cooling for the customers.

Hydro power plant, solar panels, wind turbines, combined heat and power generators are kinds of micro grid for distributing energy. Modern micro grid have the ability to store energy in batteries or electric vehicle charging stations[51], [52].

The concept of micro grid was first developed in 1882 by Thomas Edison when he built his Pearl Street Station. At that time there were no specific norms for how electricity should be distributed, so he adopted as he went along. Edison's station produced at most 6000 KWDC that served few city blocks only.

The glow of the micro grid declined as people were able to extend electricity over long distances, although they were paying more for the equipment energy-production and getting low efficiency with frequent power outages[53], [54].

As a real example for the utility and vitality of integrating the Micro grid in our energy systems, we take the case of the damage created by the super storm Sandy hit USA in 2012 putting about 15 states including New York in darkness for many weeks and left eight million citizens without lights, except the buildings that were using the micro grid. After, this the decision makers gave more attention to the micro grid system.

For more accurateness and convenience, it is recommended if the micro grid has diversity energy production from multiple sources. For more details, in case the solar cells malfunctions or it is a windy time the system switch from solar to fuel cell [55].

Introduction of Micro grid in the daily consumption and reducing the combustion of fossil become a necessity in a time where the demand on energy is increasing in high correspondence with the demand on fossil fuels that will lead to decrease in the ratio of stocks in wells and increase in the cost for extracting them. An example of the real efficiency of the micro grid is expected to play a main role in improving electricity for about 600 million people in Sub-Saharan Africa who currently have lack electricity[56].

How does Micro grid work?

Before the integration of the current sophisticated Micro grid, a classical Grid consisted of the simple connection between homes and buildings with central power sources. This interconnectedness intend that any failure in a part of the grid will affect all other parties.

The present Micro grid is the optimal solution for problems related to natural disasters, where it can operate on its own local energy generation such as batteries and/ or renewable energy sources.

In terms of functionality, a Micro grid is connected to the grid at a single point of common coupling which maintain the same level of voltage. This connection is the switch that separate the micro grid from the main grid automatically or manually and operate it temporarily in island mode.

Micro grid varies in shapes and sizes so it can power a single facility or a large area. It is not only used for emergency cases when the grid is off, also it is used to cut costs, to be energy Self-sufficiency and give communities access to clean energy which is environmentally friendly.

The aim of the Micro grid (μ G) is to integrate renewable low- carbon generation technologies with high efficient Combined Heat and Power (CHP) system depending on the climate and topology of the region [57][58][52].

From the above given information, the three characteristics of the Micro grid can be described as [59]–[61]:

- **Locality:** Can be located near the customers and the power will be more efficient by avoiding electricity capacity weakness from delivering power over distances (8 to 15% from transition).
- **Independency:** although the micro grid is connected to a several grids at the same time, but they can automatically switch and run independently due to a sudden shortage in one source, this operation mode is known as island mode.
- **Smartness:** the advanced micro grid, known as micro grid controller in a sophisticated way controlling energy consumption by getting cleanest and greatest electricity reliability in lowest prices.

Moreover, micro grids are more feasible economically and technologically, for example the cost of residential solar declined from \$5/watt to \$2/watt from year 2010 to 2017.

There are several types of micro grid which vary and evolve according to the markets, regulations and technology changes[54], [56], [62]:

- Campus Micro grid: which are commonly Combined Heat and power (CHP) and more in corporate campus. University and military campuses.
- Island Micro grid: Islands, small or large, prefer to introduce renewable energy and energy storage into energy production because of the high cost of importing liquid fuel.
- Military Micro grid: since most of the military operations are in remote areas, so relying on diesel fuel will weakness these operations due to the challenges of transporting fuel through hostile area. For these reasons adoption of solar PV and energy storage into military energy system is the aim for the United States Department of Defense (DOD).
- Community Micro grid: This kind of micro grid is commonly used in developing nations for getting electricity.
- Remote Micro grid: Diesel was dominating the remote micro grid long time but the solar storage is incorporate recently.

2.3. 1 Diesel generators:

Diesel generator (DG) operates by burning fossil fuel which is diesel to produce electricity for a single home or a large compound like malls, college campus and hospitals. The Diesel markets are increasing globally in developing countries because of the lack of infrastructure in remote areas and expand industrialization. Figure 15 describes the global market share of the diesel geenrators by sector of application, where we notice the commerical has the highest rate of use for this kind of electricity supply [63].

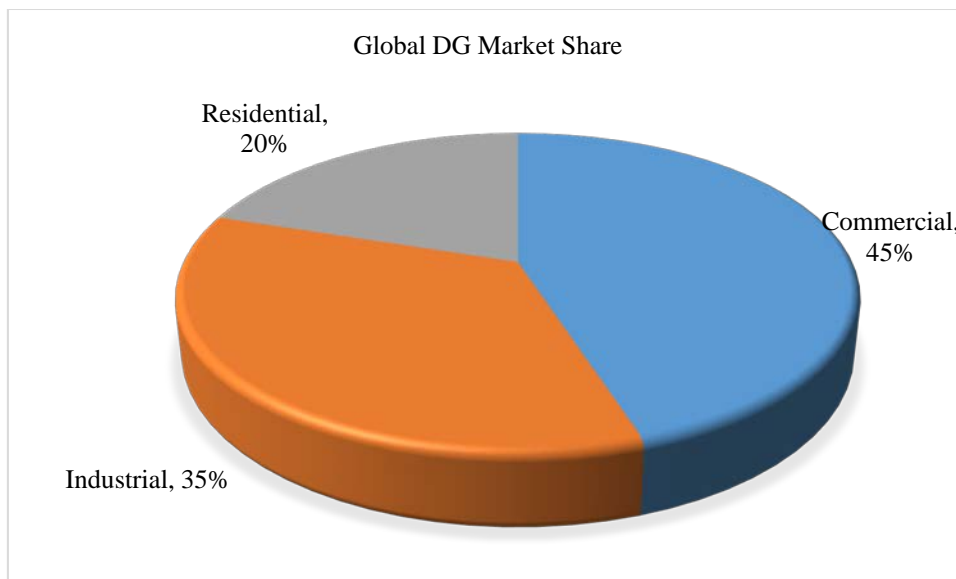


Figure 15: DG incorporation by sector of applications

In some cases and due to the possibility of long hours of electricity shortage, DG must be installed with a very specific conditions to allow the proper function. Also DG is expected to operates under extreme climate conditions like humidity conditions up to 100%, varieties temperatures from -15°C till +60°C and altitudes from sea levels up to 2 500 meters [63].

Looking the aspect of operation the DG for a long time then regular maintenance is frequently require to assure the right operation of the components. Below we give an overview about the different available DG in the market and their applications[64]–[66]:

- Small DG or low power generators are mostly used where in 2019 these devices accounted for 43.7% of the market revenue in the United States where their presence is mainly in the commercial and residential sectors. DG with capacity below 80 KW are used in residential homes to cover the electricity shortage and assure the operation of vital devices like water pumps, water purifiers, AC units and others.
- Medium power DG is used as emergency power backup systems in small-scale commercial and industrial sites in developing countries.
- High power DG is used in remote areas where there is a huge requirements for continuous power supply and these high capacity generators play the main role in power supply for in distant region where connecting to power grid is very difficult.

Where Lebanon stands: Micro grid presence and domination of Diesel Generators

Starting by a short description about the Lebanese economy and its direct influence on the power sector, where this economy is yet in a developing stage where the public sector contributes only with 25% of the total demand and the private sector covers the remaining 75%. Starting the 1990s, just after The Lebanese civil war, a great economic recovery took place and push up the GDP per capita to 353%. The Lebanese GDP has risen in a regular manner excluding 3 years 1996, 2006, 2007 till the year 2010 where it felt down to 7%.

The Lebanese citizens get most of their energy produced and consumed from imported sources since Lebanon doesn't produce any of these conventional energy sources and the renewable sources don't exceed 2% of energy production for consumption. Energy consumption in Lebanon is mainly shared between industrial, residential and transportation sectors, figure 16, that employed 87% of the total energy [46], [67].

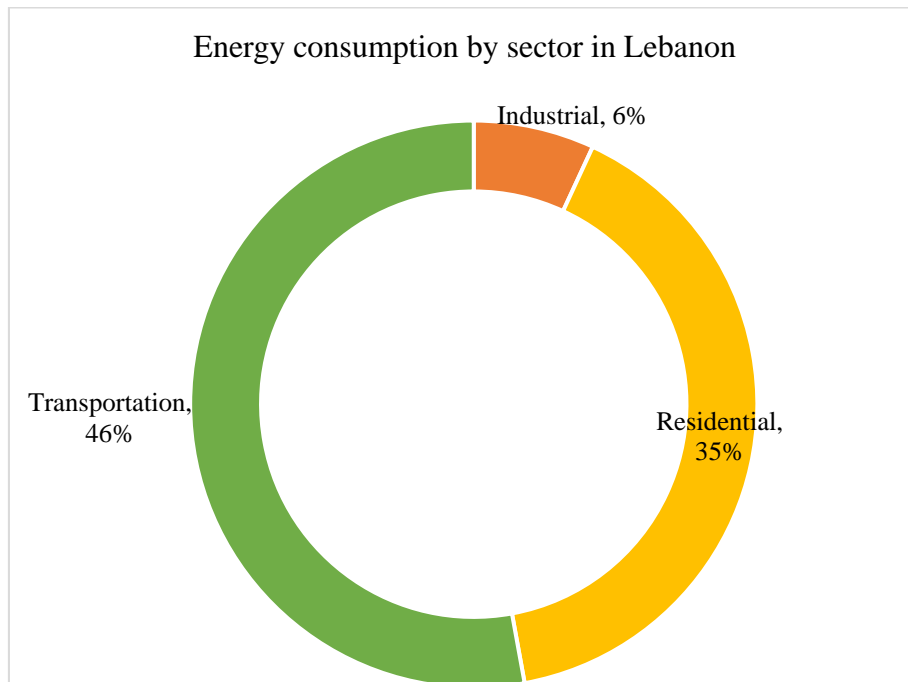


Figure 16: Distribution of Energy consumption by sector in Lebanon

Electricité du Liban (EDL) is responsible for producing, transporting and distributing of electricity in Lebanon, but after destruction of the power infrastructure by the civil war, EDL faced a shortage of more than 34% in the produced energy, this shortage is due to nonpaid bills and illegal connection to the utilities (around 20%) in addition to technical problems (14%).

With these hard conditions, the Lebanese government had decided to buy electricity from neighbor's countries (Syria and Egypt) to fill this electricity gap and later on they have been placed by mobile energy supplies placed on ships. Clearly this sector had always a serious problems and weakness that demand a radical long term solutions[68], [69].

Refugee's exodus to Lebanon has put more pressure on the weak electricity sector and lead to an increase on electricity demand due to rising loads from hotels, renting residences, moreover, the serious problem comes from the fact that a large number of the refugees are living in uninhabitable buildings or tents so that they get electricity in an illegal way. This illegal connection don't affect only the paying bills, but it results in a technical damages to the grid which means more maintenance and reparation costs [45].

The weakness in Lebanese electricity sector affects negatively other sectors since it is a cross cutting element:

- 1- Health care institutions and hospitals have relied more on Diesel Generators due to the insufficient supply hours or the poor quality of the electricity supplied.

- 2- Having dark roads because of lack of electricity which leads to security problems, therefore, the municipalities have made unique initiatives to light the roads through renewable energy.
- 3- The pressure on the public schools after the Syrian displacement had led to provide double shifts for the education of the Syrian students, in return, the electricity bill has doubled also.
- 4- Environmental and health costs are also paid due to the lack of electricity because the alternative to it is the DG. Fuel is also used inside houses for heating and outside for transportation.

The Lebanese citizens were obliged to light the dark hours in any way since the gap between electricity supply and demand in getting bigger, this gap has increased from 19% in 2008 to 33% in 2014. So the DG was the easiest way but more expensive solution for health and economy. The Lebanese consumers are paying two bills of electricity where the DG's bill is double the public electricity's bill [69], [70].

The level of the CO₂ emissions per GDP in Lebanon is higher than the world average where the power sector is responsible for 51% of the total GHG emissions. From this 51%: 32% from EDL generation, 16% from the DG whereas the rest through consumption fuel for cooking and heating.

The gap between electricity demand and supply was replaced by DG that realize noise, pollution-they are of direct link for PM emissions- and it also constitutes a material burden on the citizens. The big shortage forced to have DG almost in every quarter in Beirut where the owners of these generators used them as a private business with high income without any regulation or monitoring from the government. The worse scenario with this invented solution to cover the electricity shortage that these Diesel generators are located near the residential and sometimes in the basement of the building [71], figure 17, creating a daily worry by the habitants from the emitted pollutions and sometimes the security risk. Although good to mention that in 2018, the DG have served 1.08 million customers with 39% of the total electricity production.



Figure 17: DG network installed between building in Lebanon (Reuters 2019)

2. 4 Renewable energy and availability in Lebanon:

2.4. 1 Hydro power Source

It is the most renewable source used worldwide based on the nature water cycle, hydropower generation depends on building dams or large reservoirs to collect water in order to drive turbines for energy production. It is a flexible source of power generation especially when there is a reservoir, electricity can be generated any time and upon request. Hydro power produces 19% of world's electricity that account 77% of the electricity generated from renewable sources.

In the world there are 25 countries that depend at 90% on hydropower for electricity production and others like Norway are more advanced in this matter and reach 96% of its total energy production. In the Hydropower generation domain there is 12 countries that rely totally on hydropower for electricity supply where Canada, U.S and China have the largest hydropower generation capacity.

It is characterized by long lifetimes range between 30-80 years and sometimes more. The water used to drive the turbines are not consumed, it returns to its main source which is the river, moreover, hydro power may assist the use of water for other purposes, for example flood control, facilitate the supply network for drinking water that make it a real source of sustainability [72]–[74].

There are three types of hydro power plants mostly used of which the size and capacity can be developed to produce more energy:

- Run-of River which depends on the size and time of river flow, such projects have little or no storage capacity behind the dam.
- Reservoir where the capacity of these reservoirs can be small or very large depending on the construction method and its size. The venture of the hydro power reservoir is to store water behind the dam to de- couple generation from hydro flows.
- Pumped storage used when the peak- electricity is off, so the water is pumped from down to the top of the reservoir in order to keep stability and flexibility of grid services from the pumped storage plant.

As for the Lebanese situation in hydropower and despite all regression in this sector, it stills the main source of renewable energy generation in Lebanon compared to the very low amount generated by other renewable sources. There are 5 hydro- electric power plants distributed among the Lebanese mountains from north to south.

Litani is the main power plant, figure 18, located at the Litani-River which is the longest river in Lebanon and its annual flow of approximately 920 million cubic meter and it was classified as a good source of hydro-electric energy.

The others plants are smaller than the Litani. From year 2000, the instability of energy production from these hydro power plants was obvious due to the irregularity in annual rainfall. Rain and snow fall affect the production of hydro power plant, another negative point is the huge investment for the construction phase. But the positive sides are the zero CO2 emissions, high efficiency and low operation and maintenance costs with long life cycle of generating units [67], [75]–[77].



Figure 18: Litani hydro power plant (by litany.gov.lb)

2.4. 2 Solar energy source and explored system in Lebanon

Solar energy is one of the most popular and accessible source of renewable energy and largely used for heat and electricity purposes:

- Heat and thermal energy: used to heat water in many applications, e.g. residences, buildings and to heat spaces used inside greenhouses.
- Electricity production by Photovoltaic (PV) or Concentrated Solar Power (CSP), PV or CSP usually are not connected directly to main utilities (public grid sector) and used in remote locations.

Many consider solar energy as an added value to the economic while others consider her effect as negative looking the cost/production ratio in a period of global financial crisis and the context of sovereign debts. Thus, benefits from solar energy on the economy of the countries are still considered as a debate subject [78], [79].

Regardless the debate on the economic feasibility of the Solar energy production, there are many reasons to develop and encourage the use of this renewable source which plays a main role in the scenarios of gas emission reduction that have been set in the Blue MAP Scenario of IEA Energy Technology Perspectives 2010 which was to limit the global warming by 2°C.

The goal of the Blue MAP scenario related to CO₂ emission is to halving its level by the year 2050.

Solar energy sources are the most widely used among renewable energies and exhibited the fastest growth in these scenarios. One of the characteristics of solar energy is the unlimited potential in energy production that is why it makes the largest additional contribution to GHG emission cuts. By the year 2050, solar electricity generation will reach 25% of the global electricity production, the demand on solar energy is growing very faster than other renewable energy sources looking to its accessibility[80], [81].

Solar Thermal exploration in Lebanon

Lebanon is one of the countries rich in solar radiation, known as 360 days with sunny weather, an estimation of 3000 h an annual average irradiation of 5.01 KWH/m²/day. Although, Thermal and Photovoltaic (PV) panels still used in a very low level due to the monopoly of EDL for the power generation sector and the lack of governmental plans and support for this subject .

The solar thermal sector in Lebanon represents the main part of the total solar energy applications and basically it is fully supported by the donation of friendly countries like China, Greece, Spain Sweden and Turkey, also by the assistance of the local and international NGOs (non-governmental organizations). Therefore, the majority of the solar thermal systems applied in the market is for residential individual uses, figure 19, with 61%, 24% for the collective solar thermal systems installed in residential buildings, 10% for commercial centers and 5% for retails[82], [83][84].

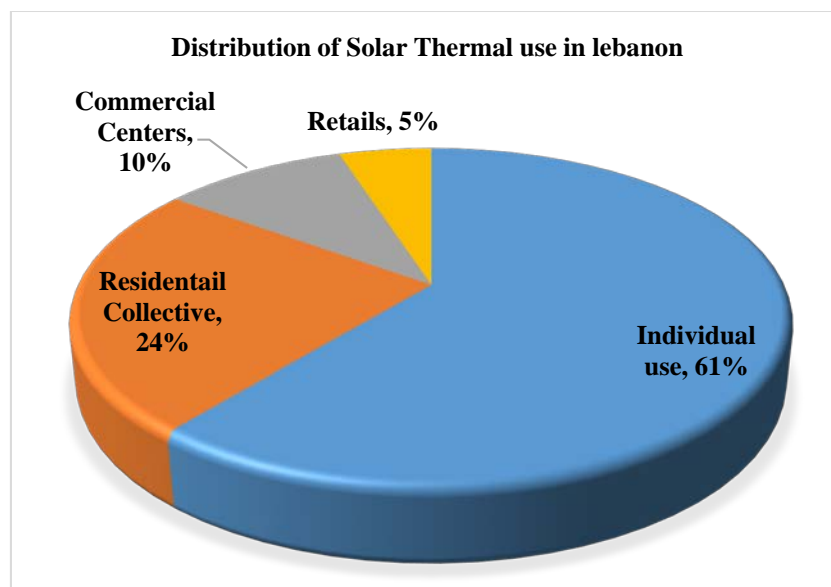


Figure 19: Percentage share for the Solar Thermal Applications in Lebanon

Using the solar water heater in Lebanon has increased significantly in the last 2 decades, e.g. the large number of units of solar thermal that were installed over different regions in the country, with the support of CEDRO-UNDP Project, which produced 133 000 kwh/year saving 19 000 Liter of diesel fuel, and the payback period is between 3-5 years[82].

Photovoltaic solar energy (PV) in Lebanon:

The installed capacity in Lebanon from PV was about 56.37 MW in 2020 representing a significant increase compared to 0.34 MW in 2011. Figure 20 represent the evolution of installed PV in Lebanon between 2011 and 2020 [85].

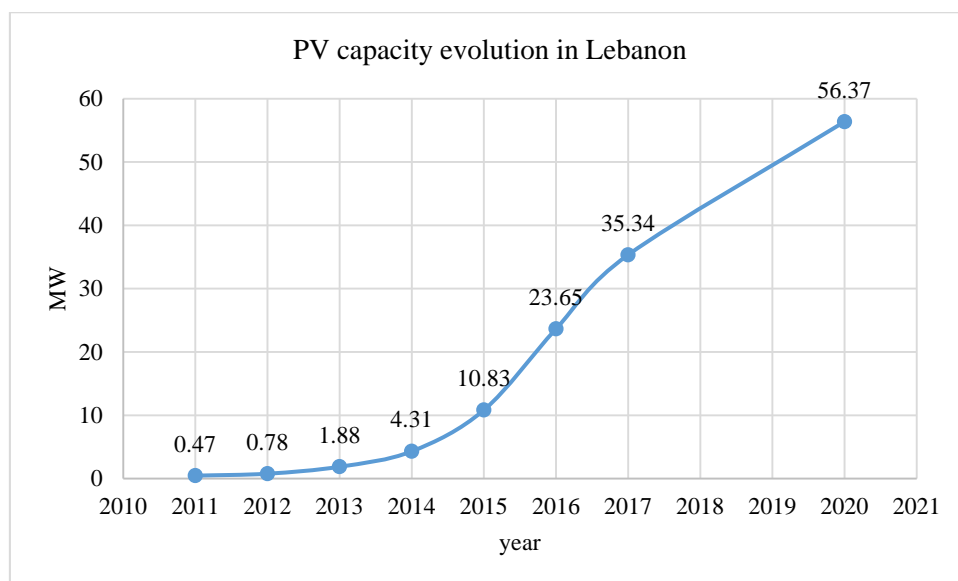


Figure 20: Evolution of installed PV capacity in Lebanon between 2011 and 2020

Between the largest private PV plants installed in Lebanon is found in the commercial center ABC, where 4,000 m² are covered, figure 21, by PV panels that provide 0.45 MW estimated to be equivalent of lighting 500 houses. Beside Similar project assures renewable energy for around 25 years, it reduces the load on EDL electricity.



Figure 21: One of the Largest Private installed PV Plant in Lebanon (ABC Achrafieh)

Another large solar project installed by the Government and consists of a PV farm placed on the walls edges of Beirut's river, figure 22, is able to produce 1.08 MW to supply around 1000 houses.



Figure 22: Beirut River Solar Snake solar project

Thus, To reach the goal of producing clean energy Lebanon there must more encouraging and supporting for such programs because this sector is still not yet well developed and needs a lot of improvements[86].

2.4. 3 Wind energy:

Wind power is the third popular option in renewable energy domain and its power capacity has been grown up to 23.6% from 2004 to 2010 worldwide. In the USA the total energy produced from wind power was 1.8% while the future plan is to increase the use of wind power by 20% of the total energy by the year 2030. The development of technology has made wind energy more cost efficiency, the cost of wind farms or individual turbines paid once for the device and the installation after that the costs are very low or almost zero since there is no need for much technical maintenance[51], [87].

Till the year 2012, the wind power capacity did not exists although there were many projects developed by the Ministry of Energy and Water to produce 60-100 MW of wind power, to date none of these projects were implemented. Now there is no clear and serious policies from the

government to invest in wind energy and the existing wind turbines in Lebanon are installed by personal initiative for residence electricity or small companies.

2.4. 4 Biomass (bioenergy):

Biomass is the largest energy source after coal and oil in the world. Waste treatment in Lebanon is a real dilemma, while it can be turned to a real treasure for our energy production by converting into electricity, heat and natural fertilizers.

The daily residential waste are estimated about 4200 tons and the non-residential waste (commercial and industrial) about 600 tons. Waste recycling can be a good source of electricity and cover 30% of the total country's needs. In Lebanon, there are four big waste's landfills (Quarantinah, Bourj Hammoud, Naameh and Normandie) were a high gas storage potential have been shown from them [88], [89].

2. 5 CONCLUSION

Due to the global increase demand on energy, most of the developed countries have moved towards investing in renewable energy production in order to reduce emissions. This can be applied by using Micro-grids for distributing energy as hydropower plant, wind turbines, combined heat and power generators. Where modern micro grid have the ability to store energy in batteries or electric vehicle charging stations, it can operate on its own local energy generation.

Private Diesel generator (DG) operates by burning fossil fuel which is diesel to produce electricity and mostly used in developing countries because of the lack of infrastructure in remote areas and expand industrialization. During this study we have observed that almost half of the electricity demand is produced from private diesel generators since Electricité du Liban (EDL) have shortage in electricity supply and by time the gap between electricity demand and supply is getting bigger.

The hydropower is the main source of renewable energy generation in Lebanon while the other sources are applied but only based on personal initiative, although there were many governmental projects with the help of other countries, but none of them have been completed.

CHAPTER 3: ENERGY EFFICIENCY IN LEBANON: IMPROVING ENERGY STATISTICS FOR SUSTAINABLE DEVELOPMENT

Abstract

Reducing of carbon emissions rely mainly on Energy efficiency that has a direct influence on the amount of used fuel for the production of electricity. A comprehensive study for the real situation of Energy efficiency in Lebanon was realized by collecting data related to this matter form ministries and international organizations. During this study it has been concluded that Energy efficiency in Lebanon remains relatively modest despite the great potential for energy savings in all consumption sectors.

Our recommendation is to adopt urgently a competent Energy Efficiency plan to be adopted in Lebanon at governmental level, especially that the country is facing a high inflation for primary energy consumption since 2011, refugees' crisis, which affected the all of the country's economic activities.

During this study it was reported the fact that primary energy is consumed mainly in the form of final energy and shared mainly between electricity generation by EDL, transport and residential sectors. Also it was noticed a continuous grow in the consumption for household appliances particularly for the air conditioners. All the above confirm the need to work on more efficient equipment at the household level but also to reduce these needs through better thermal insulation of buildings and more widely on urban cooling solutions.

3. 1 Introduction

Energy efficiency became the last years a major issue for reducing CO and CO₂ emissions, reducing the energy dependence of countries relying on the importation and moderating the effects of rising oil prices.

The energy efficiency policy in Lebanon remains relatively modest despite the great potential for energy savings in all consumption sectors. However, some actions have been carried out for several years but still the country did not reach an acceptable level in this regard. So far, several initiatives have been taken to disseminate the use of solar water heaters, including direct financial aid under conditions and loans at zero interest. In 2011, the Council of Ministers

adopted the NEEAP (National Energy Efficiency Action Plan) made up of 14 actions to promote and adopt Renewable Energy and Energy Efficiency solutions.

Also, financial mechanisms to encourage the implementation of energy efficiency and renewable energy projects have been established, in collaboration with the European Union and the association of Lebanese banks; this made it possible to make funds available to grant loans at very low or zero interest rates to finance projects in the various sectors, particularly the industry.

3. 2 Unexpected Demographic Change Context

From 2011, a massive influx of refugees to Lebanon (at least 1.5 million people). In 2017, the number of officially registered refugees was still close to one million, representing 25% of the total population. Refugees now represent a quarter of the host country's population, with more than 220 refugees per 1,000 Lebanese inhabitants, according to official numbers of the World Bank in 2019. Evolution of populations in Lebanon from 2000 is represented in figure 23 [90].

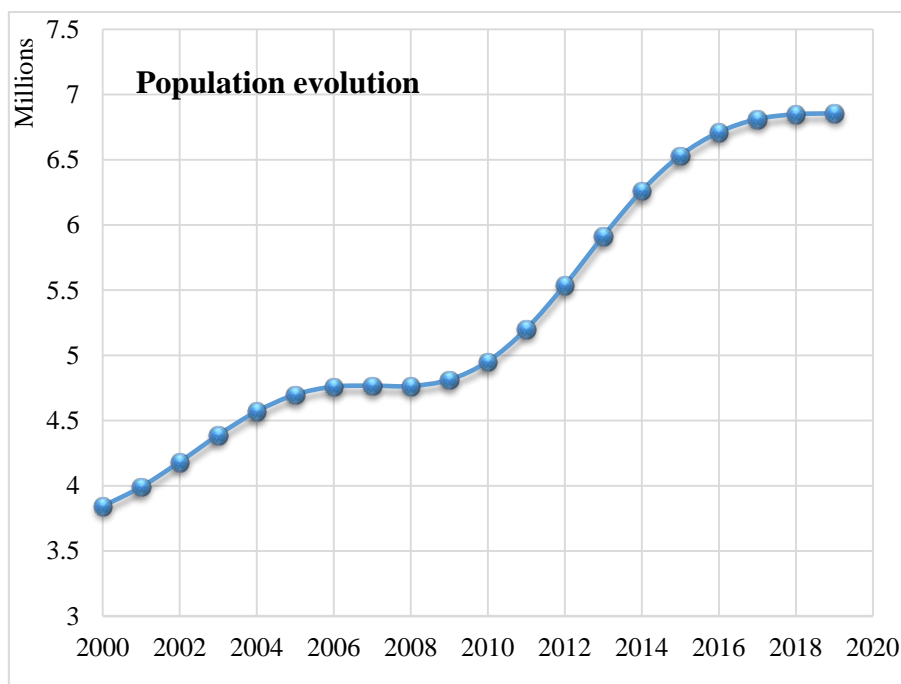


Figure 23: Lebanese Demography evolution after 2000.

Lebanon is increasingly overwhelmed by the influx of refugees and host communities are nearing breaking point, the United Nations High Commissioner for Refugees has warned in 2015.

Lebanon has emerged as the country in the world with the highest density of refugees per capita and struggling to keep pace with a crisis that shows no signs of slowing down.

The impact on Lebanon is immense, notes the UNHCR organization. The country is experiencing severe economic shocks due to the population growth that has occurred, including a decline in trade, tourism and investment and an increase in public spending. Utilities are scrambling to meet growing demand. Health services, education, electricity and water supply as well as sanitation facilities are particularly put to the test [90], [91].

According to the World Bank, the migration crisis cost Lebanon \$ 2.5 billion in lost economic activity in 2013.

Local communities are the ones feeling the pressure of the influx of refugees the most, with many villages and towns now hosting more refugees than Lebanese. Critical infrastructure across the country is strained, affecting refugees and Lebanese alike. In 2018, sanitation facilities, the power grid and waste treatment services are severely weakened, clinics and hospitals are overwhelmed, and water and electricity resources are depleted. It is increasingly recognized that Lebanon needs long-term support in terms of sustainable development, especially in terms of energy production and environment, in order to survive the crisis [92].

Obviously all international and local organizations have recognized that the burden of electricity consumption by refugees weighs heavily on the electricity grid. Indeed, the demand of refugees absorbs almost a third of the electricity production capacity of Lebanon (EDL), according to a report unveiled by the Ministry of Energy and the United Nations Development Program (UNDP) in April 2017 [45].

In Lebanon, the gap between electricity supply and need is staggering. While the peak demand from Citizens can reach 3,100 MW, the average electricity supply is only 1,530 MW. Under these circumstances, citizens face power cuts of up to 12 hours a day outside of Beirut, forcing consumers to depend on private generators (Diesel Generators, DG).

According to the same published report by the ministry of Energy and Water, the arrival of refugees since the start of the civil war has added 486 MW to the already existing needs, an additional burden on the transmission and distribution networks. The 486 MW is a national average calculated from field visits carried out by the authors of the report in July 2016 to examine the electricity consumption of a sample of 340 refugees' families and that of 60 public infrastructures such as hospitals, schools, and municipalities. The report's conclusions are based on the total number of refugees counted by the General Security (1.5 million), considered more appropriate than the latest estimate of the United Nations High Commissioner for Refugees (1 million). The calculation of their consumption is also based on an average

electricity supply of around 14 hours per day, according to Electricité du Liban (EDL) [71], [83], [93].

The direct impact of the refugees represents 447 MW (including 15% technical losses), to which we add the indirect impact on schools and municipalities of 39 MW, to arrive at a total of 486 MW. This figure represents approximately 30% of EDL's power generation capacity, based on a total generation capacity of 1,620 MW.

3.2. 1 Illegal connections

In addition, the rate of illegal connections, figure 24, to EDL by refugees and therefore unpaid bills reaches nearly 45% on average throughout Lebanon.



Figure 24: example of illegal connection on the EDL's grid (Ref. BBC, Dec 2019)

These facts represent a financial burden on the national economy of more than 330 million dollars per year, advanced by the Ministry of Energy and not included in the report, includes 222 million dollars in arrears for EDL and 111 million dollars spent on private generators by the Lebanese [94].

Our recommendation, in the short term, is to reduce demand by improving energy efficiency, notably through the distribution of low-consumption lamps, Photovoltaic panels and solar water heaters. The strengthening of the EDL distribution network is also necessary to reduce technical losses and improve the quality of electricity and the level of voltage. In the med term,

that is to say over 5 years, we are encouraging decentralized generation in areas where demand reaches 10 MW and switch more and more to the renewable production.

3.3 Economic context

The Gross domestic product GDP (Y) is the sum of consumption (C), investment (I), government spending (G) and net exports (X – M).

$$Y = C + I + G + (X - M)$$

GDP in Lebanon has been studied for the period 2000 to 2019, where after data analysis it can be divided into 3 main intervals:

2000-2006, the GDP has a moderate average annual growth rate of around 3.2 %

2007-2010, has experienced a strong recovery in economic activity, of the order of 9.25 % per year, thanks in particular to the construction sector which represents more than 75% of industrial activity.

2011-2019, as a context of the refugees' crisis and the demographical change the GDP was dramatically decreased to 0.4 % (annual).

The Average value of the GDP for the total period 2000-2019 is 3.14% [95], [96]. Figure 25 illustrate the Average annual growth rate of GDP for the 4 main periods, for the period 2000-2019.

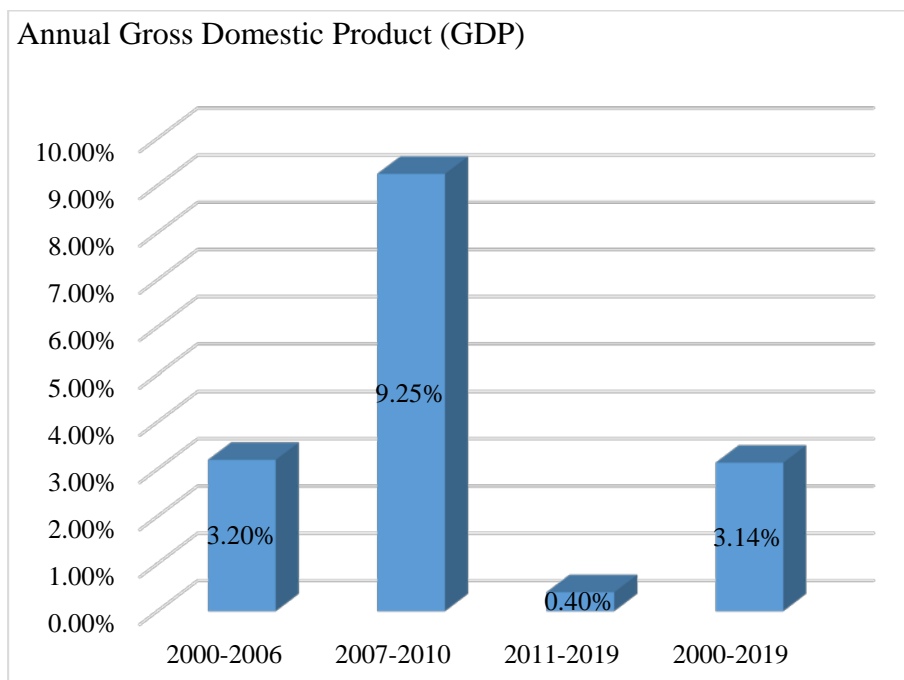


Figure 25: Annual Gross Domestic Product (GDP)

Figure 26 represents the variation index of the GDP with respect to the population evolution between 2000 and 2019 where the refugees' negative effect on the GDP growth is shown clearly after the 2011.

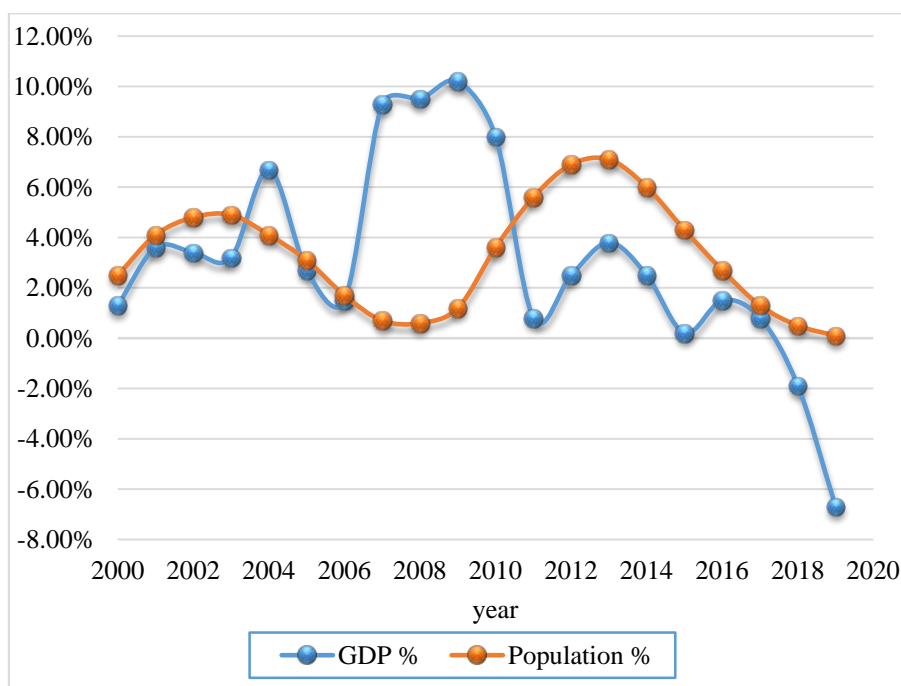


Figure 26: GDP and population variation index

3. 4 Energy context

Energy policy in Lebanon is subject to a few recovery plans that have not been able to see the light till our day. Therefore, the energy supply is experiencing chronic problems which have had a negative influence on growth in general.

As an example of the absence of solutions is that Energy production by natural gas in Lebanon still missed despite the promises and plans announced. Concerning electrical energy, the supply is characterized by an almost constant production of the national company EDL, for the past 15 years, while the demand recognizes a significant growth exceeding the 8% for certain years; as a result, supply is in permanence lower than demand, increasing in cut hours occurs and reach it is peak summer. Need of missing supply has to be compromise by the production of electricity on a private basis (Diesel Generators, DG) supplied to citizens with a high rate where the cost per kWh produced can exceed the 30 cents, almost unbearable for certain industrial sectors. More dramatically this unaffordable cost may goes up to \$3,750 or \$ 4000 per family per year to pay for covering the shortage of electricity production by the Government sector (EDL) [89], [97].

From all the above data we conclude clearly that integration of energy efficiency plans and solutions must be integrated and applied, especially where experiences in many countries have shown that benefit from energy savings can give a great results. But if we look closely on ground we see that lack of coherent plans and inclusive programs have intended to a negative conclusion where energy efficiency in Lebanon remains far below expectations.

3.4. 1 Trends in energy consumption

Until 2005 The demand for **primary energy (PE) and final energy (FE)** have experienced a moderate grew, where around 8 % more demand for both in 2005 compared to 2000.

In 2006, country passed a significant drop on the demand due to internal events where the level of consumption has decreased to 2.3% for primary energy and -5% for final energy.

From 2007 to 2010, the growth of demand for primary and final energy picked up to reach 35% and 30 % respectively more than in 2000 and this is related directly to the construction sector that was highly active during this period.

From 2011 the country faced a very important inflation for primary consumption that can be explained by the refugees' crisis, which affected the all of the country's economic activities.

Figure 27 represent the increase in primary and final energy consumption measured yearly for the period going from 2000 to 2019 [83], [98], [99].

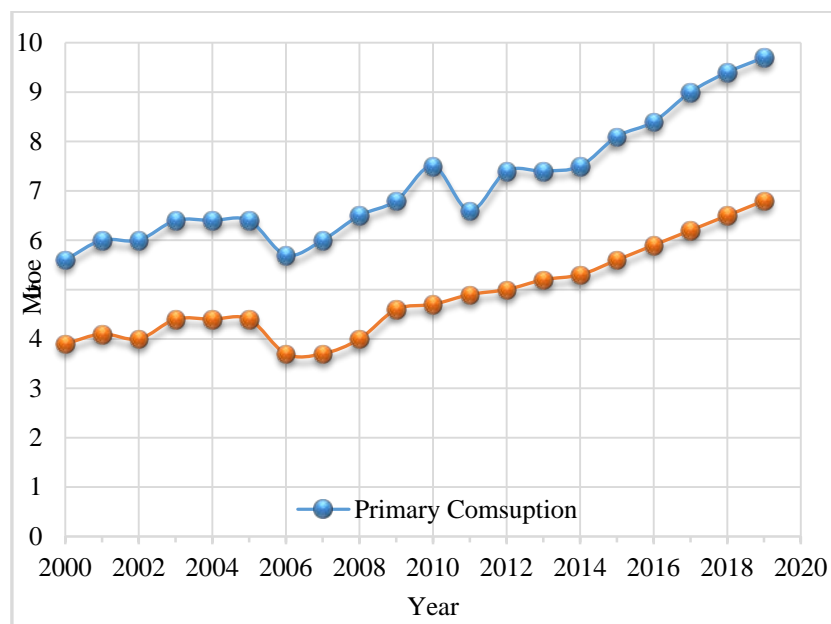


Figure 27: Primary and Final Energy Consumption

Figure 28 gives the plot for the **distribution** of the primary energy consumption per energy type and for three slots of time until 2000, 2012 and up to 2019.

From the data of figure 4 we can conclude that Lebanon's primary energy consumption has changed little since 2000. Oil represents the main energy in the consumption (95% in 2019). The other energies contributions are respectively coal (1.9% in 2019), biomass (1.7% in 2019) and primary electricity (hydraulic and renewable) (1% in 2019).

Until 2019, Lebanon has no fossil fuel resources. Its hydrocarbon needs are fully covered by imports, especially oil [100].

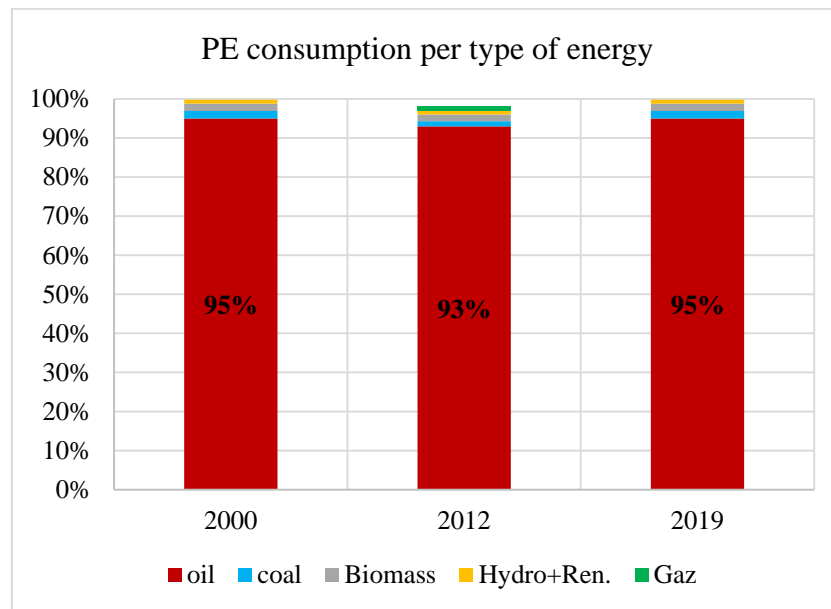


Figure 28: Distribution of Primary energy consumption by type of energy

It can be concluded that petroleum products accounted for average 94% of primary energy consumption for the period between 2000 and 2019.

Most of the primary energy in Lebanon is imported in the form of finished products from abroad (petroleum products and electricity).

Primary energy is consumed mainly in the form of final energy and shared between 2 main categories where for the national production of electricity, and most of which is of thermal origin consume 30% of the remaining 70% of this FE is distributed between the below sectors:

- Transport
- Residential
- Industrial
- Tertiary
- Agriculture.

Figure 29 gives the distribution of final energy per sector for data measurement in 2019 [101].

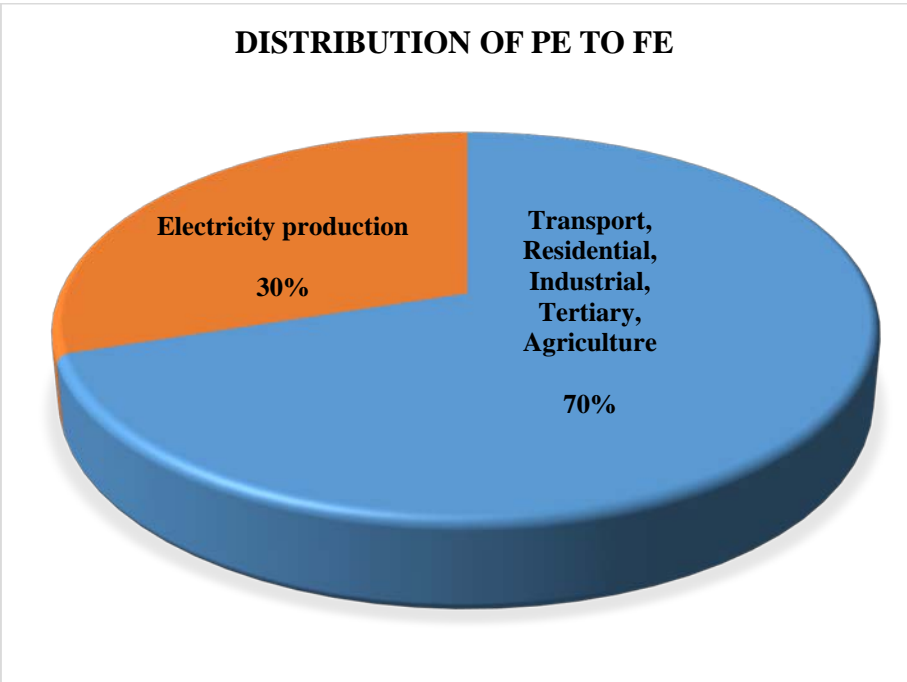


Figure 29: share of the primary Energy Consumption between electricity production and uses as final energy by different sectors

Figure 30, provides the distribution of final energy per sector, where if we exclude the industrial sector, all remaining sectors have an increase in the consumption since 2000, especially residential. This increase was mainly driven by households, under the combined effect of population growth important with the influx of refugees since 2011 and the rise of private consumption. The households alone consumed 33% of total final energy demand in 2019. The increase in the share of the buildings sector has come at the expense of the industry, whose consumption fell in relative terms from 19% in 2000 to nearly 6% in 2019.

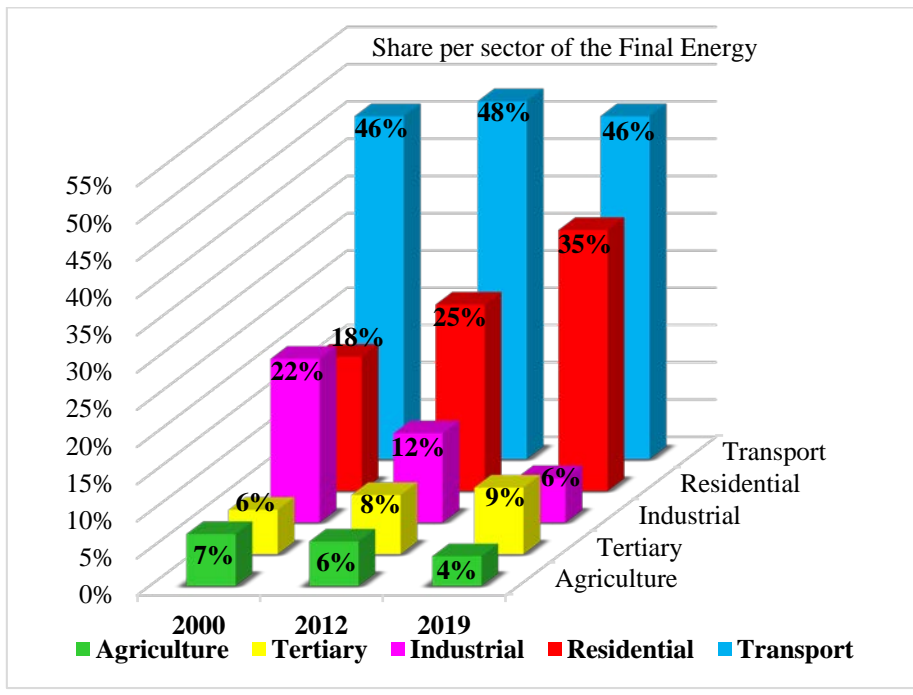


Figure 30: Distribution of final energy consumption per sector

In order to better understand the distribution in the final energy consumption per sector we have determined the share of each sector with respect to the total primary energy of the country for the year 2019, where results are presented in figure 31

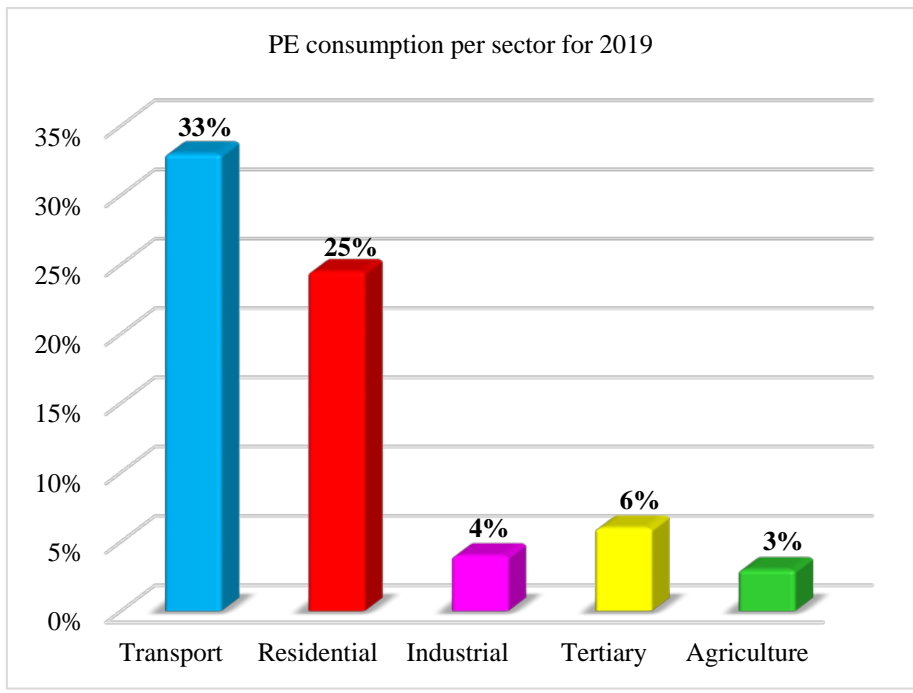


Figure 31: Share of the Primary Energy consumption per sector of activity for the year 2019

Always the transport and residential sectors are the champions of consumption with respectively 34% and 25% of the primary energy imported by the country, a worrying values

that need immediate governmental intervention in order to reduce the pollutant consequence of both concerned sectors that are very well known in their harmful effect on the public health

3.5 Study for the FE Consumption per Sector

3.5.1 Energy efficiency values in transport sector

The transport sector in Lebanon contribute around 23% of GHG emissions where most of the cars depend on gasoline. This sector is the second largest energy's consumer, one of several reasons for this high consumption which in turn lead to high rate in emissions is that most of the cars in Lebanon are old, fuel intensive and pollutants.

The rate of car ownership is very high in Lebanon compared to other countries like Turkey and Jordan, 4.34 individuals/car- 2.53 individuals/car- 1.66 individuals/car respectively. 85% of the total number vehicles in Lebanon is for private cars [102], [103].

Lebanon was ranked the 17th world wide with respect to passenger vehicle this is because the public transport sector in Lebanon is very poor, the buses are old, no fixed stops and no clear schedule for bus shelters, that is why citizens prefer to have their own vehicle to move comfortably. There is an estimation that the number of private cars will increase more by time which will lead to an additional increase in GHG emissions.

As it is mentioned, the transport sector constitutes the first place in the final energy consumption of Lebanon, where measurement shows an average value about **half** of total FE consumption for the last 20 years. This issue is related to the fact that in Lebanon the government has completely ignore the facilities of domestic rail or maritime transport since 1974 [8], [103].

In 2019, the transport consumption is dominated by the road sector characterized by private cars, trucks and vans that consume 64% and 26% goes for public buses and governmental vehicles, figure 32 while the air transport represents only 10% consumption of the transport sector in Lebanon. [71]

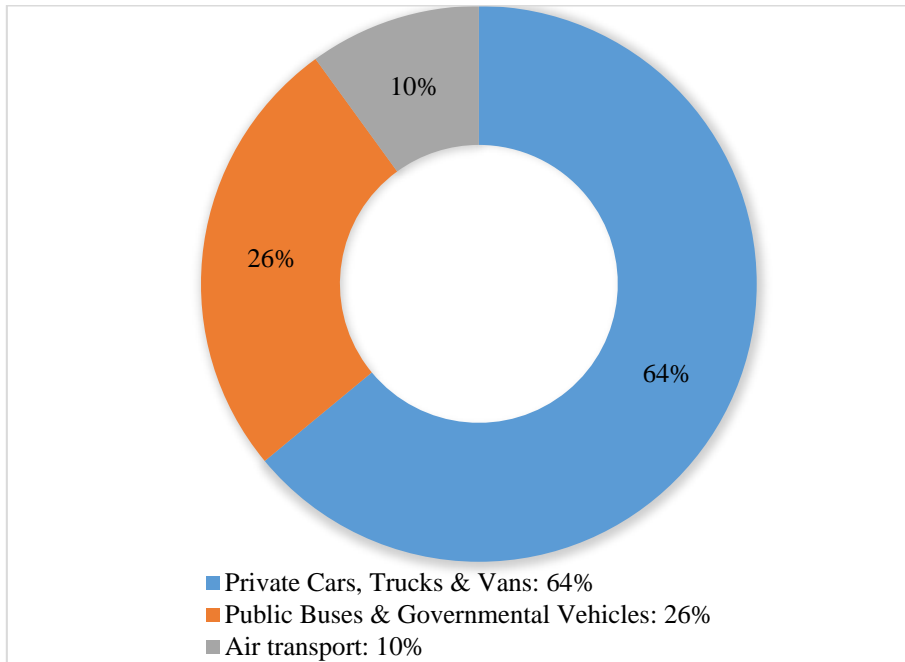


Figure 32: Distribution for the energy Consumption Per category of transport from the FE.

In order to better understand the effect of road transport on the final energy consumption in the country we have calculated the road share values with respect to the national uses of FE, where it has been found the part of ‘private cars, trucks and vans’ alone is 30% followed by the Governmental vehicles 12.5% and the Air transport has always the smallest amount with a share of 4.8% [104].

Figure 33 shows the share of each transport category in the total national final energy consumption in 2019.

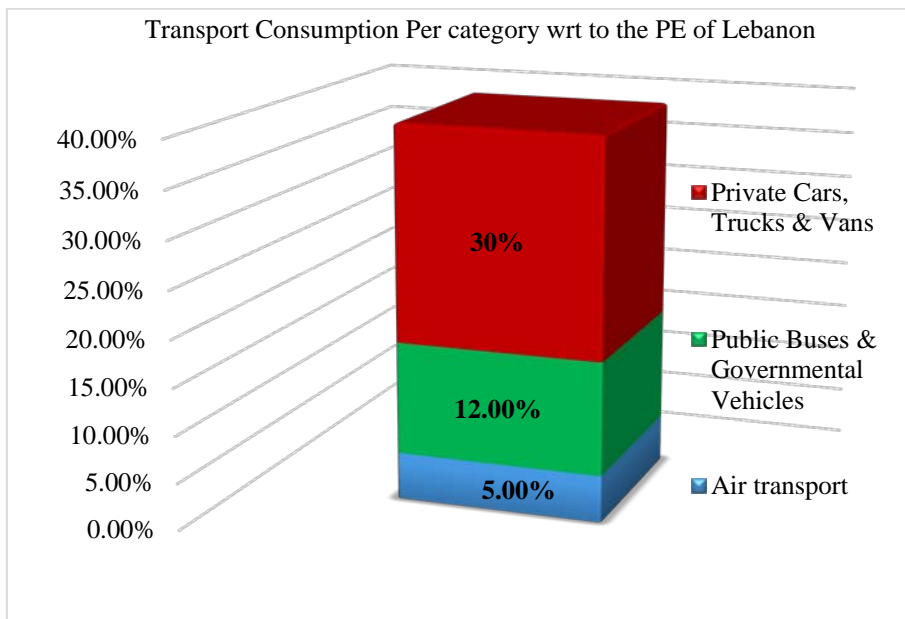


Figure 33: Transport consumption of Primary energy in Lebanon for each sector

The combination of the ‘private cars, trucks and vans’ and the Governmental vehicles gives 42.5% consumption of the total final energy of the country, a values that uncover the amount of polluted substances generated by the vehicles motors and subsequently explain the elevated number of diseases related to the exposition to the monoxide of carbon in the big cities in Lebanon [104].

3.5. 2 Energy efficiency values in residential

The Lebanese Residential energy consumption have increased due to fast development of urbanization, climate change and living standards. The unsuitable performance of the existing buildings is the main cause of this increase in energy demand, e.g. inadequate day lighting and the excessive use of air conditioning units.

The Lebanese buildings energy consumption is expected to reach in 2030 the level of 250% compared to the energy consumption in 2010. Any improvement in this sector will have a direct refinement on environmental conditions and growth of national economy, since the residential sector represent 47% of the total energy produced [105].

The residential sector is considered as one of the main energy consuming sectors in Lebanon, accounting for 35% of final consumption in the country in 2019. This is also one of the main challenges, especially given the significant demographic growth in Lebanon after the refugee crisis in 2012 in addition to the improvement in household living conditions.

Households in Lebanon knew an average increase of final energy (FE) consumption **from 18% in 2000 to 35% in 2019**. This high values reflects intense energy uses and equipment ownership rates. Trends in household final energy consumption also differ significantly between periods of the year. The final energy consumption has tended to grow in Lebanon for almost the last 20 years, but in a much exaggerated way since 2012, the year of the refugee crisis in the country [106].

This increase in the FE Consumption in Lebanon is to the opposite of the **European countries** for which it has tended to decrease since 2010 under the effect of energy efficiency policies and more adherence to the energy saving concept by the citizens

The above mentioned increases in the Residential sector share in the consumption of final energy (FE) is considered as a serious matter in terms of pollution, environmental protection and further public health. In this immense evolution in the FE consumption, electricity represented the largest consumption share in household where it is use has been considerably magnified since the refugees’ crisis (starting 2012) [67], [107], [108].

Our study for the share of consumption of the Final Energy has been divided into 2 critical intervals of time:

- **2000 to 2012:**
 - o Electricity represented 33%
 - o Petroleum Product (PP) 38%
 - o Liquefied Petroleum Gas (LPG) 16%
 - o Biomass 13%.
- **2012 to 2019:**
 - o Electricity showed an important magnification up to 47%
 - o Petroleum Product (PP) has decreased to 30%
 - o Liquefied Petroleum Gas (LPG) also decreased to 12%
 - o Biomass to 11%.

Figure 34 shows the distribution of the different final energy consumption for the 2 intervals of time.

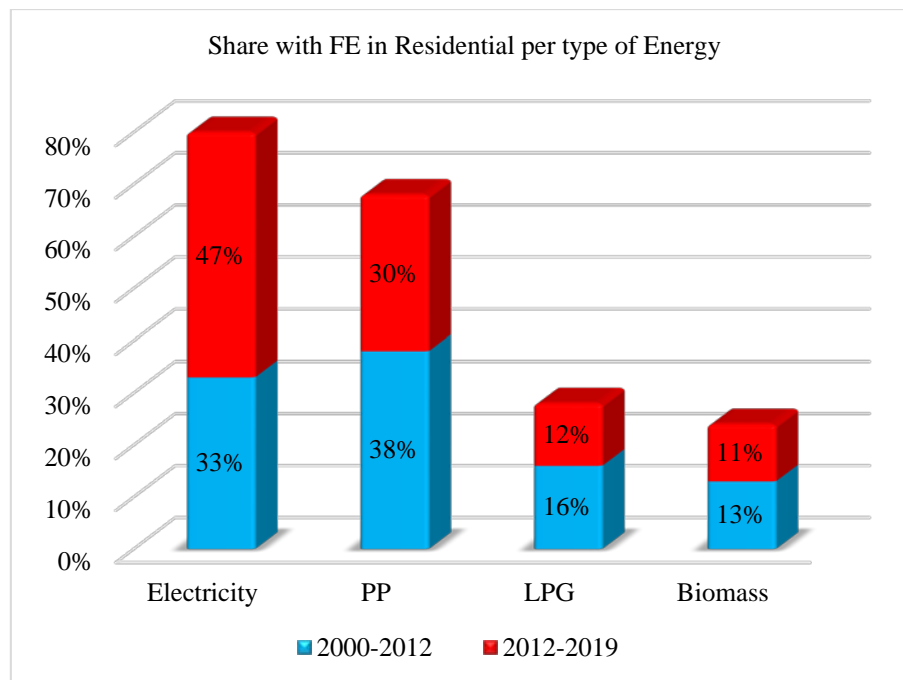


Figure 34 Distribution of final energy consumption in residential (Electricity, PP, LPG and Biomass) for the 2 intervals of times 2000-2012 and 2012-2019.

Thus, electricity use has the greatest part of the increase in the residential consumption of the final energy where it reaches 47% in 2019 compared to 33% in 2000, an additional 14% of use which is considered very important with respect to a small country like Lebanon.

Consumption values with respect to the Primary Energy (PE) of the country

In order to better understand the influence of each type of energy used in the Lebanese household on the consumption of the Primary energy in the country, we have determined the

values of these consumptions with respect to the total consumption of the PE in the country for the year 2019 (Figure 35).

Analysis shows that in 2019 the share part of residential is 25% of PE where it has been observed that electricity is consuming alone 12% of the Primary Energy of the country followed by the Petroleum product with 8%, a values that reflect the real crisis caused by the demographical explosion since 2011 [109], [110].

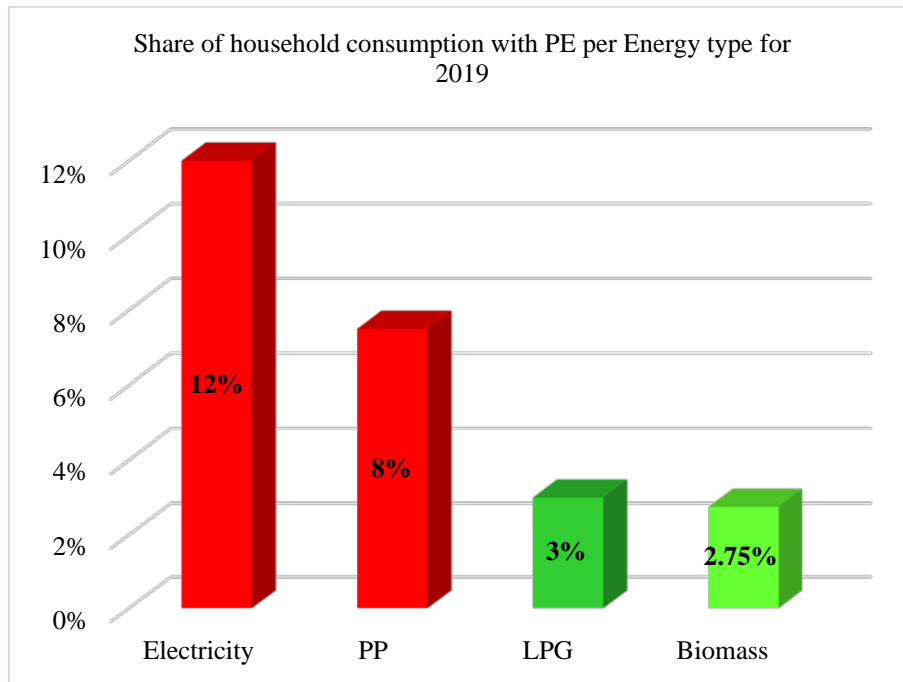


Figure 35: Consumption of Primary energy by households by type of Energy

Significant increases in air conditioning Installations

During this study we have noticed a continuous grow in the consumption for household appliances and lighting, but the most striking evolution in the country is the equipment in air conditioners which increased by 12% per year in 2019 alone. (Very high values about air conditioning in household energy consumption).

These results can be explained by the excessive increase in the rate of equipment for air conditioners; the number of equipped households increased in Lebanon between 2010-2019, at a rate of + 6% per year, to reach 75% of households.

These trends strongly confirm the need to work on more efficient equipment at the household level but also to reduce these needs through better thermal insulation of buildings and more widely on urban cooling solutions [111], [112].

3.5. 3 Energy efficiency values in industrial in Lebanon

Energy Supply remains major concern at many levels for the Lebanese industry, where the energy bill cause a heavy load on the industrials on the absence of continues supply from the Governmental sector (EDL) or they have to be rescued toward private electricity production by Diesel Generators.

Many initiatives of financial mechanisms to support the industrial sector in Lebanon have been settled with the aid of the European Union, the participation of the Central Bank of Lebanon and the Association of Lebanese Banks. These mechanisms aim to provide loans at zero interest to finance energy efficiency and renewable energy projects in Lebanon [101], [113].

Data Collection shows that distribution of final energy consumption of industry by branch is dominated by the cement industry and the second place is for the food industry where the chemicals branch has faced a serious fall in the last 20 years (Figure 36).

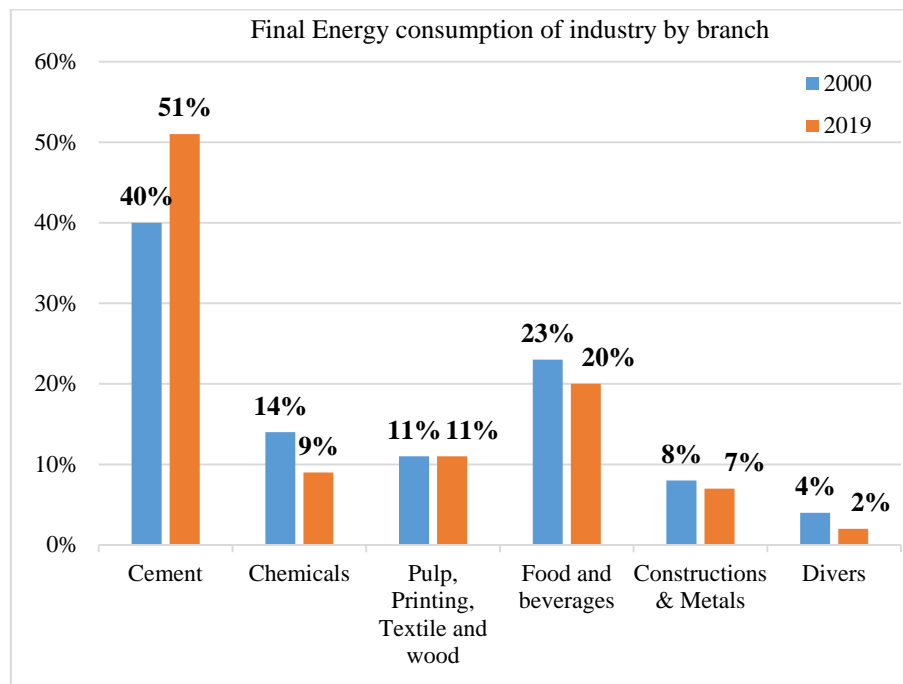


Figure 36: Industrial consumption for Final Energy between 2000 and 2019

3. 6 CONCLUSION

Energy efficiency (EF) became the last years a major issue for reducing CO and CO₂ emissions. Energy efficiency in Lebanon remains relatively modest despite the great potential for energy savings in all consumption sectors. Lack in the EF in Lebanon related to many reasons such as the unexpected demographic changes induced by the high number of refugees merged to Lebanon and the negative consequences for a country that is not prepared to acquire this enormous flow.

Also it was obvious that the primary energy in Lebanon is consumed mainly in the form of final energy and shared between production of electricity, transport, residential, industrial, tertiary and agriculture. There are several steps that have been under implementation for several years, yet we have not seen any real improvement toward the goal.

CHAPTER 4: LEBANON'S ELECTRICITY FROM FUEL TO SOLAR ENERGY PRODUCTION BY THE USE OF MICRO GRID SYSTEM

Abstract

Since 1924, Lebanon planned to use renewable energy and in particular hydraulic energy to produce the national need of electricity. Until the beginning of the 70, many steps have been achieved by the government where in 1974 around 41.5% of the Lebanese electricity was produced from hydroelectric stations. Unfortunately since then and due to the instability in the political regimen, electric plants and networks suffered from destruction, aging, increased demand, hacking and many other deterioration factors. Therefore and based on all the last mentioned troubles the electric sector in Lebanon transformed to be the major economic and environmental problem.

This chapter consists in presenting and analyzing the actual state of the electric sector in Lebanon emphasizing on its negative impact on air pollution and on the development of factories and small enterprises. Therefore, it will be shown that the problem with the electrical sector is essentially due to the old networks easily hacked, strong reliance on fuel-based electricity, which leads to the increased air pollution without meeting the energy consumption demand. This underproduction of electrical energy leads to the development of a parallel electrical private sector also based on fuel burning what worsened air pollution problems despite all the measures taken by the governments to switch to greener electricity production. A case study on electricity consumption in different locations in Beirut is also presented and used to prove that shifting from fuel to solar production will decrease the economic impact of electricity. Hydroelectric energy was not considered due to a decrease in the precipitation level that made it difficult to produce enough energy from rivers and due to the high cost of rehabilitation and upgrading.

4. 1 1. Introduction and literature review

Like most modern countries, Lebanon is suffering from energy problems at the levels of production, consumption, and saving. The leading consequence being environmental degradation and air pollution. Unfortunately, one of the major causes of air pollution in Lebanon after transportation is the electric sector due to the classical and the non-developed way of generation.

Electricity in Lebanon is assured through a governmental institution Electricité du Liban (EDL,) that was established in 1964 and up to 90% of the Electricity to the Lebanese territory. EDL produced 1700 GWH of electricity, in the 1974 where 41.5% coming from hydropower. This sector, which was expected to turn a part of the energy production in Lebanon to renewable energy resources such as hydraulic power and solar energy[67], [114]–[117], but unfortunately it has been transformed to be a deadly pollutant weapon[42], [68], [118] . In reality, due to the civil war that started from 1975 and lasted to 1990 the military actions have destroyed several thermal power stations and transmission lines. This act pushed people to rely on several pollutant means of energy production, like diesel generators (DG) that do not respect the international norms (bad quality of used Fuel and complex maintenance task in failure without real preventive maintenance plan) and also the production of thermal energy for water heating by burning pollutant metals (wheels and furniture).

After the 90's the Lebanese electricity generation relied mainly on fossil fuel and suffered from many technical and non-technical losses such as illegal connections and meter manipulations.[47], [69], [89], [117]. In 2003, the production of electricity reached 10.5 TWH where 87% of this electricity is produced with gas oil, diesel and fuel oil and the remaining 13% of the electricity produced with hydropower plants. Good to mention that production from hydropower plants dropped to 4.5% [75] in 2009 due to lack of maintenance and aging in the materials.

Despite the effort made after 1992 to reactivate this sector, the generated power was not able to meet the permanent increase of the society demands. Furthermore, this already old and weakened sector had to face the challenge of meeting the needs of millions of unexpected refugees from different countries who flew to Lebanon in a very short time. Therefore the ministry of energy was not able to organize and implement solutions to the over demand and consumption of energy. The newly imposed problem on the Lebanese government coming from the over consumption created a serious shortness in the supplied hours of electricity where in less than one year the number of population has raised by approximately 25% of the total citizens living in Lebanon [45].

The above-mentioned causes led to having a blackout among the year that could reach in average 13 hours per day in many Lebanese regions; that pushed the consumers to find alternative solutions by developing private networks in parallel to the governmental sector (EDL).

Power generation in Lebanon in terms of capacity, efficiency and productions has been investigated by many organizations such as the united nations, the World Bank, the International Monetary Fund, Greenpeace, [45], [115], [118]–[121] and it has been proven that

this sector needs rehabilitation, reorganization and servo by renewable energies. In addition, it was agreed by the local and international investigators that last mentioned reforms are strictly necessary to achieve the below targets:

Decrease air pollution therefore reducing its destructive impact on human health, animals, plants, soil, building materials in other words on the entire ecosystem of the country that has seriously been damaged by the non-responsible practices over a period of 20 years.

Promote enterprises and revive the industrial sector, a step that will open the door to new work opportunities, competitions and productions that fit the international norms.

In order to help in the planning and the solution proposal for the above recommendations submitted by the investigators we have realized a case study for the electric consumption of Lebanese foyers for March 2020 till February 2021 that almost correspond to all seasons. A numerical analysis proposed is based on a real data measurement for electric consumption taken along a 24 hours for sixteen houses.

Data collection for the study were realized by installing power-meter devices, for energy consumption monitoring and registering, in the electricity's room control of two complex of Buildings located in the South of Beirut and the East of Baabda District of Mount Lebanon Governorate, Beirut City.

A comparison between the Diesel generators supply and the likely alternative clean source, in our case we have targeted the Micro grid, was carried to verify the possibility of covering the shortage of the EDL supply. Obtained results showed clearly the benefit and advantages of switching to Micro grid energy production.

4. 2 Current situation of electric sector in Lebanon

The Lebanese institution for electricity production (EDL, Electricité du Liban) was established in 1964, it assured the distribution of electricity to up to 90% to the Lebanese territory.

In 1974, the EDL institution produced 1700 GWH of electricity where 41.5% of this produced power was hydroelectric, meanwhile the production coming from the small private companies was 0.296 GWH which constitute less than 0.02% of EDL production [122].

This sector, which was expected to turn a part of the energy production in Lebanon to renewable energy resources such as hydraulic power and solar energy, now is suffering from many problems at the levels of production, consumption, and saving. Moreover, it becomes the leading reason of environmental degradation and one of the major causes of air pollution after transportation due to the classical and the non-developed way of electricity generation where

unfortunately it has been transformed to be a deadly pollutant weapon. With more precision, due to the civil war between 1975 and 1990 the military actions have destroyed several thermal power stations and transmission lines. This act pushed people to rely on several pollutant methods of energy production, like diesel generators (DG) that do not respect the international norms (bad quality of used Fuel and complex maintenance task in failure without real preventive maintenance plan) [67], [114]–[117][42], [68], [123].

After the 90’s the Lebanese electricity generation relied mainly on fossil fuel and suffered from many technical and non-technical losses such as illegal connections and meter manipulations. In 2003, the production of electricity reached 10.5 TWH where 87% of this electricity is produced with gas oil, diesel and fuel oil and the remaining 13% of the electricity produced with hydropower plants. Good to mention that production from hydropower plants dropped from 11.7% in 1994 to 1.4% in 2020, figure 37, due to lack of maintenance and aging in the materials [43], [64], [67], [68].

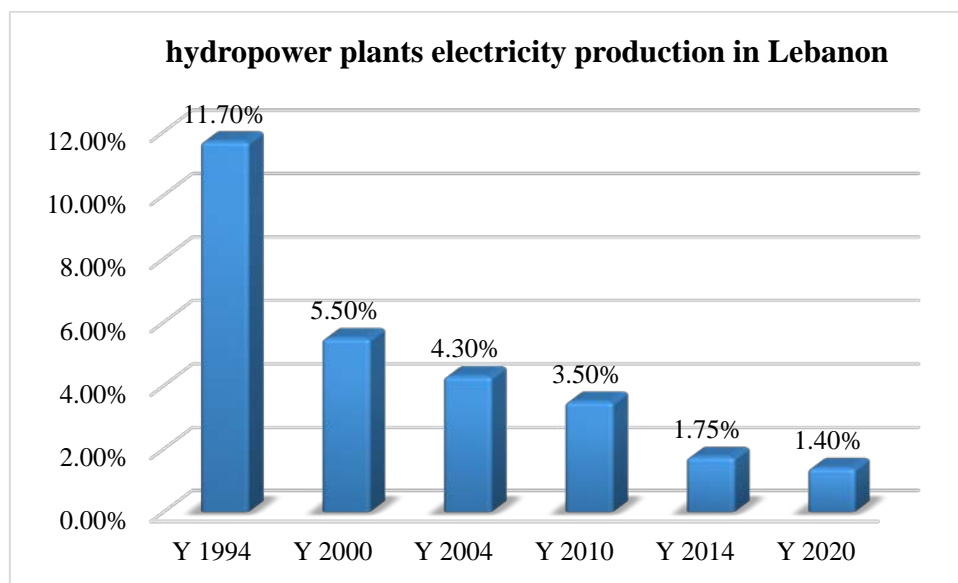


Figure 37: Variation of electricity production by hydropower plants in Lebanon

Despite the effort made after 1992 to reactivate the electricity sector, the produced power was not able to meet the permanent increase of the society demands. Furthermore, this already old and weakened sector had to face the challenge of meeting the needs of millions of unexpected refugees from different countries who flew to Lebanon in a very short time. Therefore the ministry of energy was not able to organize and implement solutions to the over demand and consumption of energy. The newly imposed problem on the Lebanese government coming from the over consumption created a serious shortness in the supplied hours of electricity where

in less than one year the number of population has raised by approximately 25% of the total citizens living in Lebanon [45].

The above-mentioned causes led to a blackout among the year that could reach in average 13 hours per day in many Lebanese regions; that pushed the consumers to find alternative solutions by developing private networks mostly based on Diesel generators (DG) in parallel to the governmental sector (EDL). Supplied Electricity by private DG is sold to the Lebanese citizens at very high rate compared to the EDL price per KW.

In figure 38 is given a comparison for prices of KW supplied by EDL, DG, Hydro, Solar and Wind, where it can be concluded the huge difference of KW cost imposed by the suppliers of private DG. From these data we can understand the immense bill paid by the Lebanese citizens where in addition to the fees paid for the EDL the DG invoice can goes up to 2.5 times the EDL cost, those numbers can explain the total cost either at economic or at pollution level [42], [69].

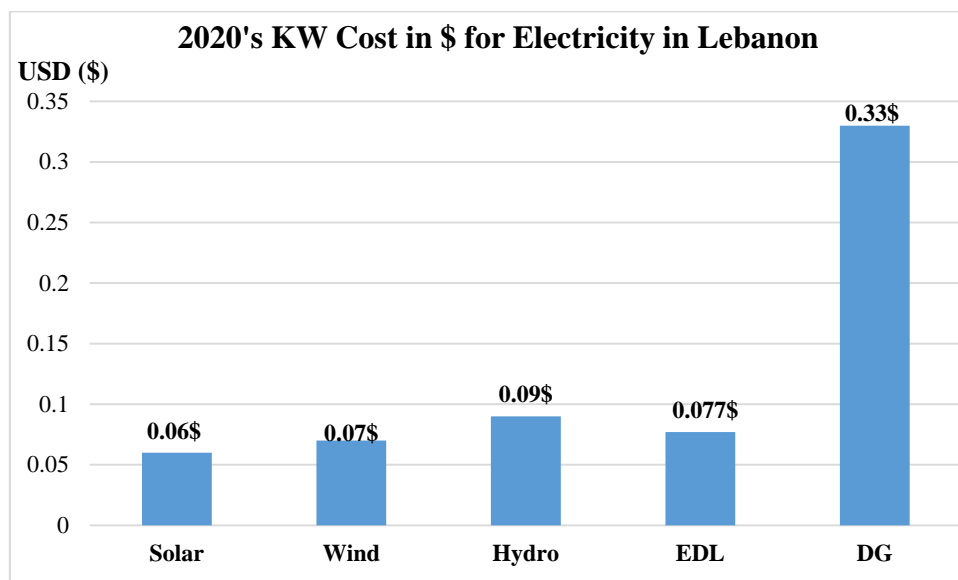


Figure 38: Prices of KW of Electricity paid by Citizens in Lebanon

Power generation in terms of capacity, efficiency and productions in Lebanon has been investigated by many organizations such as the United Nations, the World Bank, the International Monetary Fund, Greenpeace and it has been proven that this sector needs rehabilitation, reorganization and servo by renewable energies. In addition, it was agreed by the local and international investigators that this reforms are also strictly necessary to achieve the below long term targets [119]:

1. Decrease air pollution therefore reducing its destructive impact on human health, animals, plants, soil, building materials in other words on the entire ecosystem of the

country that has seriously been damaged by the non-responsible practices over a period of 20 years.

2. Promote enterprises and revive the industrial sector, a step that will open the door to new work opportunities, competitions and productions that fit the international norms

4. 3 EDL: Deficit, Shortage and Private Diesel Generators (DG)

Electricity is a major and painful problem in Lebanon which consequences reached levels that start to pose a serious damage on the Lebanese citizens and at many levels.

This dysfunctional sector at many scales, managed by the government, became a burden on public finance, on households, on public health and the total Lebanese ecosystem. Furthermore, it is still unable to supply the reliable electricity needed by industry, commerce and houses therefore imposing a significant economic and social cost.

Lebanon imports 92% of the fuel needed for energy and electricity production such as fossil fuel, in 2020, the country imported 120 000 barrels/day of refined oil products. In addition to that the Lebanese population growth was rising during the last 3 decades with an extremely high and fast percentage that reached 243% in 2020 compared to 1990, figure 39, while the energy resources remain limited and went in regression. This population's augmentation can be referred to a large inhabitation migration back to Lebanon after the civil war and the sudden rise happened with refugees after 2011. This can explain the shortage in the public sector to assure electricity for the citizens 24/24 hours where in reality the public sector can't provide more than 50-70% of the population's need, which in parallel opened the doors for the diesel generators and allow the owners of these generators to control this sector[36], [61].

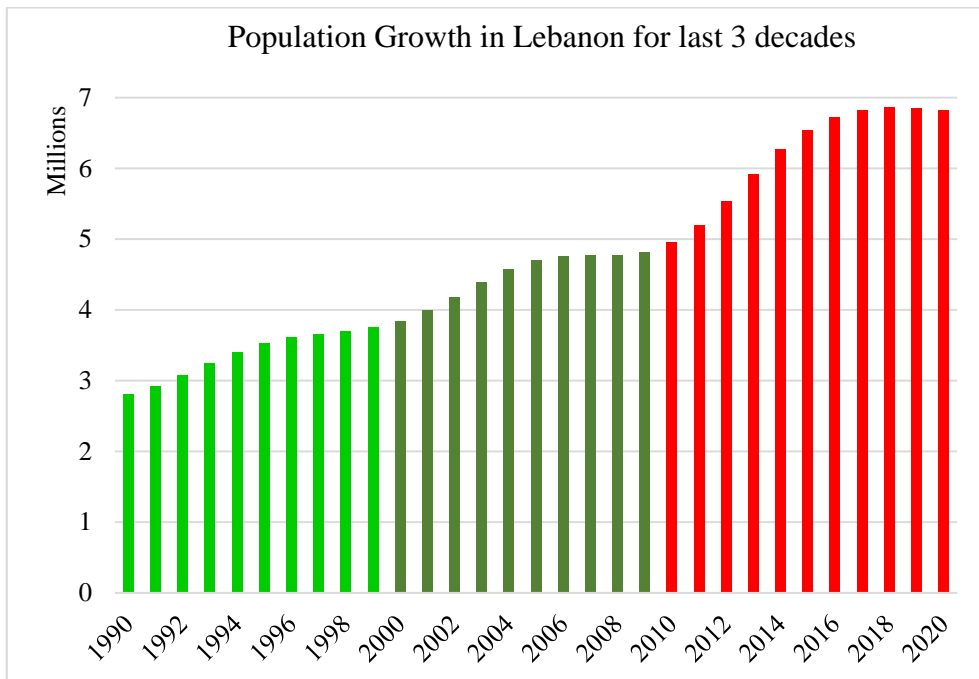


Figure 39: Population growth in Lebanon between 1990 and 2020 (World meter)

For approximately \$2 Billion/year, Lebanon generates only about 1500 MW, while the domestic electricity needs are at least twice as much. All these factors are indicators for the instability in energy market. Moreover, the Lebanese citizens are paying two bills one for the EDL and the second for the private Diesel generators (DG) where the price of the KWH of the private generators is **270% more expensive** than the KW of public electricity. Another indicator of unfair management for this sector is that in the whole Middle East region, the Lebanese are paying the highest electricity bill with lowest quality service [71].

Furthermore, the public sector of the Lebanese electricity is one of the main causes of the state's deficit and reached 40% of the total Lebanese debt in 2019 according to the International Monetary Fund (IMF). This deficit is due to many reasons such as the price of the KWH of the electricity that hasn't changed since the mid of 90's despite the fact that oil prices have increased.

4.3. 1 Challenges

Electricite du Liban (EDL) is the official company owned, solo managed by the state for the generation, distribution and transmission of electricity. This company is facing many challenges and difficulties where we highlight below the main and crucial four important challenges [89], [94], [121], [124], [125]:

- First, EDL's generation capacity is well below consumers' demand especially in the last ten years where an increase in the living population of about 1,500,000 persons have suddenly

landed in the country without any preliminary preparations or planning [45].

EDL infrastructure was damaged and disregarded after the war (1975-1990) which reduced the production capabilities. A reconstruction and rehabilitation plan for the power sector was developed and implemented since 1992 but it was inefficient and insufficient since the gap between EDL's power production and the total electricity consumption is still growing every year. According to a report published in 2018 by the international monetary fund (IMF), electricity demand increases by 500MW each five years in Lebanon, moreover the negative effect of this number on the society is aggravated by the reduction in the electricity supply. This difference between production and consumption was around 22% in 2008 and is expected to reach 56% in 2025 [71]. It is due to ageing power plants with high maintenance cost and operating below their rated capacity what leads to power outages of at least three hours per day in Beirut and up to twelve hours outside Beirut.

Some solutions have been implemented such as the rehabilitation of power plants, creation of photovoltaic and windmill farms and temporarily renting power barges. However, the green energy stations are still under construction and power outages remains the same across the country. In addition, we assist to real motivation to green energy without real management study.

To compensate the outages of the electricity the Lebanese citizens developed a networks of supplying composed of expensive private generators placed in the basements of buildings, parking lots and in alleyways near residential units. Those networks are extremely polluting, noisy and do not obeyed to international norms[126].

- Second, EDL suffers from technical and non-technical losses on the transmission and distribution grids. EDL estimates technical losses to be around 19% when non-technical losses are due to illegal connections to the network and reach 21%.
- Third, despite there was a common consensus by the decision makers in Lebanon that the electricity sector needs to be reformed completely, proven a reform still difficult. Indeed, many reform plans have been elaborated but were never implemented. The most recent attempt was in 2019 when the ministry of energy and water updated the Policy Paper for the Energy Sector developed in 2010. Cabinet and Parliament both approved this reform in April 2019 and they have agreed on four points that must reduce EDL deficits that are:
 1. Reducing losses by improving the Distribution Service Provider (DSP) framework and the distribution grid, installing smart meters and temporarily decreasing the subscription price.

2. Increasing the capacity by building new power plants.
 3. Decreasing the production cost by using gas input instead of fuel.
 4. Increasing the tariffs after supplying 24/7 electric power and adopting an automatic fuel indexation mechanism [69], [94].
- Fourth, EDL is facing a financial problem since most of the power produced is based on heavy fuel and diesel oil, which leads to high operational cost. A cost that is not entirely collected because EDL is currently applying a low cost outdated tariffs structure where the rates are unchanged since 1996 and because of the unpaid bills that constitute 5% of the total losses of the firm.

All those energy challenges affect negatively the society in different ways and at different echelons. Impact of caused drawback and consequence from the above described challenges on enterprises and air pollution was investigated in the below paragraphs [89].

4. 4 Impact on enterprises

Nowadays all businesses depend on a supportive environment that reinforce the companies' ability for improvement and development, i.e. to survive, create jobs, invest, innovate and be competitive. A reliable electricity supply is of major importance for economic growth. Therefore, electricity shortages, bad performance and the necessity to rely on high cost private generators affect the competitiveness of businesses in Lebanon due to huge economic losses [127] and lead to lost economic opportunities. This is shown by a survey conducted by the World Bank [128] in which electricity shortages are listed as the second constraint to competitiveness after political instabilities.

4. 5 Impact on public health

High reliance of EDL on heavy fuel oil and diesel oil not only increases the production cost but also leads to air pollution since burning such types of fuel generate particulate matter as well as toxic gases such as NO_x and CO₂. Moreover, the electric outages obliged the citizens to rely on private diesel generators. The emissions of such generators increase air pollution problems to the point at which Greenpeace classified the city of Jounieh located near Zouk's thermal power plant as the 5th most air polluted town in the Arabic world [119].

Those pollutants that we breathe lead to adverse physical and mental health problems such as anxiousness, depression, attention problems, increased premature death, asthma, cardiovascular disease, lung cancer and other pulmonary diseases.[42], [129]

Electric sector in Lebanon has reached a critical situation and needs efficient and fast solutions.

4. 6 Targeted contribution

There is a strong desire in Lebanon to achieve the energy transition from fossil to renewable energies. Such a transition needs to be planned and prepared by undertaking different impact studies. However, there is a lack of such studies which deal with investment opportunities, environmental damage, consumption and maintenance costs. Considering simultaneously these aspects can help establishing an economic transition plan. In this context, this chapter deals with a real case study about switching from Diesel generators (DG) to solar energy using Micro grids (MG) as an Energy Management Systems (EMS). An analytical model expressing an objective cost function to be minimized, is developed to establish an economical energy production plan switching between fuel and solar energy. A numerical example is discussed in order to illustrate the use of the analytical model.

4. 7 Electricity production's aggravation of air pollution in Lebanon

High reliance of EDL on heavy fuel oil and diesel oil not only increases the production cost for the Government but also has a serious damage on the health of the Citizens from the high level of air pollution produced by the types of used fuel that generate particulate matter as well as toxic gases like NO_x and CO_2 . Moreover, the shortage in the supplied electric hours obliged the citizens to rely on private diesel generators that intensify the pollution of the Lebanese environment. Therefore air pollution generated in Lebanon from the electricity production, by EDL and private DG, in addition to the factories and the transport sector and in particular the excessive use of the cars become one of the direct causes that harm Lebanese health and lead to serious illnesses at the level of rheumatic, coronary heart diseases, pneumonia, lung and stomach cancer. On the other side this environmental degradation is costing the Lebanese government around 170 million dollars yearly which represent 1.02% of Gross Domestic Production GDP of the country [123], [130].

In the Middle East and North Africa (MENA) countries, premature deaths related to air pollution from fossil fuels is estimated at 65,000 annually, figure 40, where the majority of the

premature deaths in the MENA region (65 0000) is directly related to the exposure to the PM2.5 followed by the NO2 and the O3. Lebanon recorded the highest rate per number of habitants of premature deaths with 4 deaths per 10000 persons, figure 41, followed by Egypt with a rate of 3.3 deaths/10000 and Syria 2.8 deaths/10000 [131], [132].

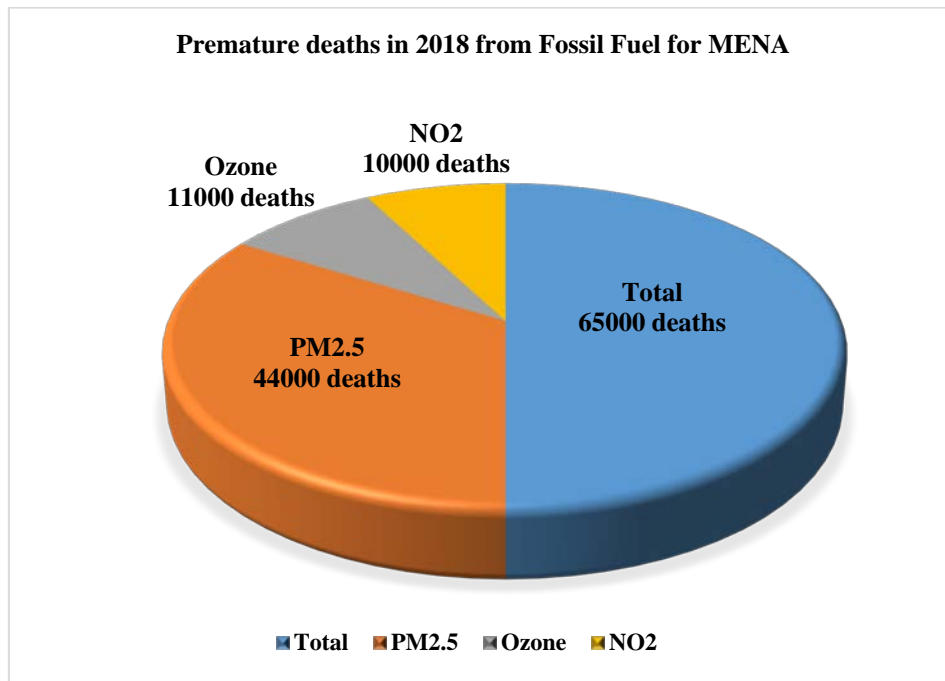


Figure 40: Premature deaths by type of pollutants from Fossil Fuel for the MENA countries

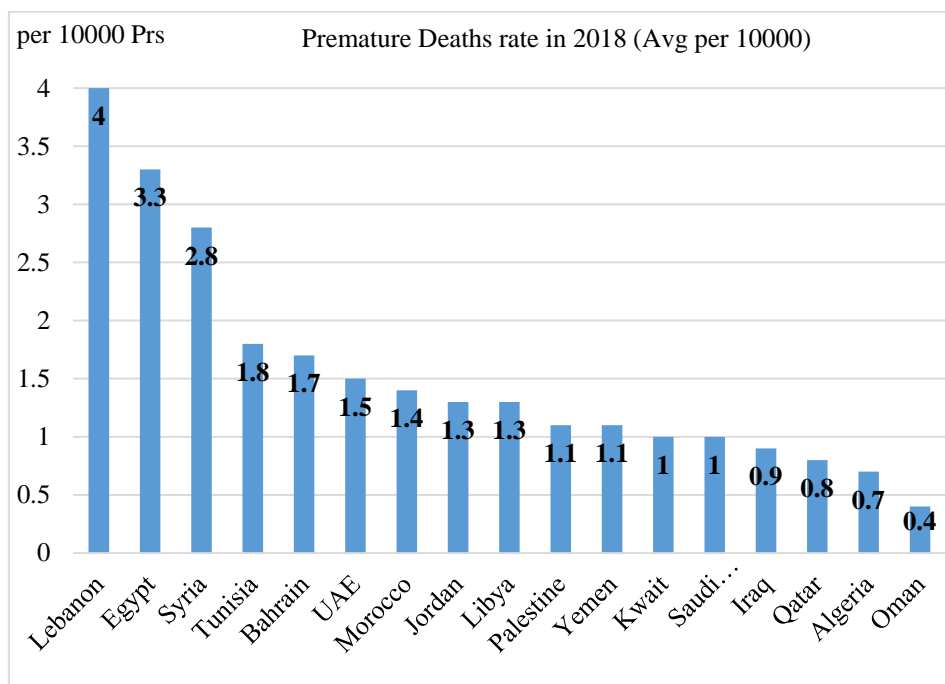


Figure 41: rate of deaths/10000 people for the MENA countries

The WHO has mentioned that 100% of the Lebanese population are exposed to pollution level exceeding the standard allowed norms, where the country was rated in 2019 the 5th among 91 countries with respect to the level of outdoor air pollution, especially in Beirut city the densely populated urban area. Another study shows that between 1082 cities in the world, Beirut was ranked in the 176th level of outdoor air pollution also. Obviously the Electric sector in Lebanon has reached a critical situation and needs efficient and fast solutions [46].

4. 8 Experimental Study: household energy consumption

In order to contribute the planning and the solutions proposal for the recommendations suggested by the investigators, we have realized a ground study for the electric consumption of Lebanese households and for different period of the years 2020-2021 that almost correspond to all seasons.

A proposed numerical analysis based on a real data measurement for electric consumption taken hourly for sixteen households by installing an AEMEC-PEL 105 power-meter devices with data logger in order to monitor and save the hourly power consumption over 24 hours and for many months. The households are in two Block-flats with 8 households for each and were nominated B1 B2, located respectively in the South and in East of Baabda District of Mount Lebanon Governorate, Beirut City.

The solution to Lebanese electric sector problems must include besides energy saving a strategic plan that involves renewable energy sources especially solar energy. In fact, Lebanon enjoys around 3000h of sunshine during a year that correspond to an average solar irradiation varying between 1520 KWh/m²/year and 2148 KWh/m²/year with the majority of the areas receiving above 1900 KWh/m²/year [114].

Renewables integration in parallel to the fuel sector of EDL will decrease the production cost from 0.17\$ per KWH to around 0.06\$ per KWH, a 35% of gain that may be invested in the maintenance and improvement of the present exciting sector which will lead to more efficient production by fuel at lower cost.

Furthermore, using solar energy will avoid fuel burning at high amount therefore, decreasing carbon footprint, air pollution and health cost. To prove the efficiency of switching to micro grid produced electricity a study was conducted to understand the cost difference between diesel and solar electricity for two sets of households.

Energy consumption (EC) for Households of two Block of Flats, given the names B1 and B2 and containing 8 residences each, were recorded over 24 hours over the period of **“March 2020 to February 2021”** in order to cover all seasons of the year. The first Block was chosen in a

town to the east of Beirut (Block of flats I: B1) and the second in a town to the south of Beirut (Block of flats II: B2).

Data Measurement, treatment and analysis were driven as following:

- March 2020: Before Lockdown time with regular lifestyle in Lebanon
- April-May 2020: correspond to Lockdown period, that will allow us to make the comparison between regular life style and complete stay for the families in residences
- June to Sept 2020: Associated to summer season
- October 2020 to February 2021: Associated to winter season

The study has considered the particularity of the COVID19 wave where the first Lockdown was imposed in Lebanon during the months of April-May 2020, and recorded power consumption in this month were treated separately and compared to the data recorded before Lockdown for March 2020. The goal of treating the data recorded during the Lockdown was to verify the rate change in the consumption when people are permanently in homes and compare it to a period with regular life style. Those changes in living styles will allow us to study and understand the consumption variation during all conditions. Both cities suffer from 10h to 12 h of electricity shortage compensated by private diesel generators.

To determine the total cost of consumed energy as well as the benefit that may be gained from switching to micro-grid, a Lab-developed simulation program run under MATLAB Software was used and allowed us to calculate the total cost of fuel based electricity generation and solar electricity production for the two block of flats B1 and B2.

figure 42 a and b represent respectively the power consumption for the eight apartments in Block-Flats 1 (B1) and Block-Flats 2 (B2) just before Lockdown for the month of March 2020.

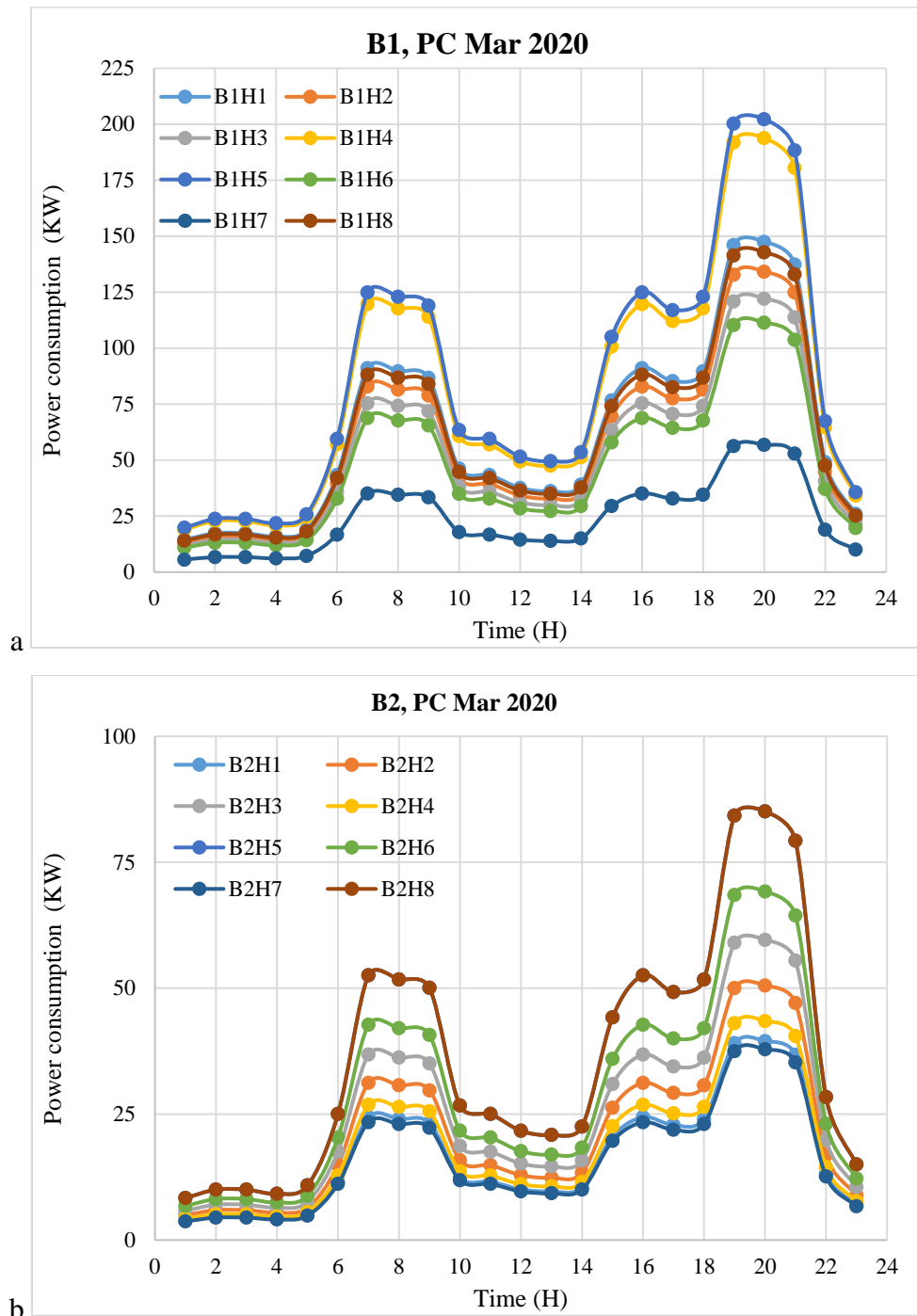


Figure 42 a and b: Power consumption (EC) for B1 and B2 for March 2020.

It is obviously concluded from the power measurement taken in March 2020 for B1 and B2 that people followed a monotony life style in this month and the use of household electricity is directly related to the presence of persons between work and home. In more details, since schools start at 8:00 AM as well as most of the jobs, the first consumption peak extending from 5:00 to 10:00 AM corresponds to the morning use of electric current (light bulbs, heater, small and large home appliances). The two other peaks correspond to the time when children are back from school (03:00 PM) and when people are back home from work, (06:00 PM)

considered as the time of evening activities (Studies, TV, use of home appliance). Therefore, curves of power consumption present typically the same pattern and daily routine.

Figure 43 represents the power consumption for the eight apartments of a second Block-flat 2 (B2) for a period of Lockdown, April-May 2020.

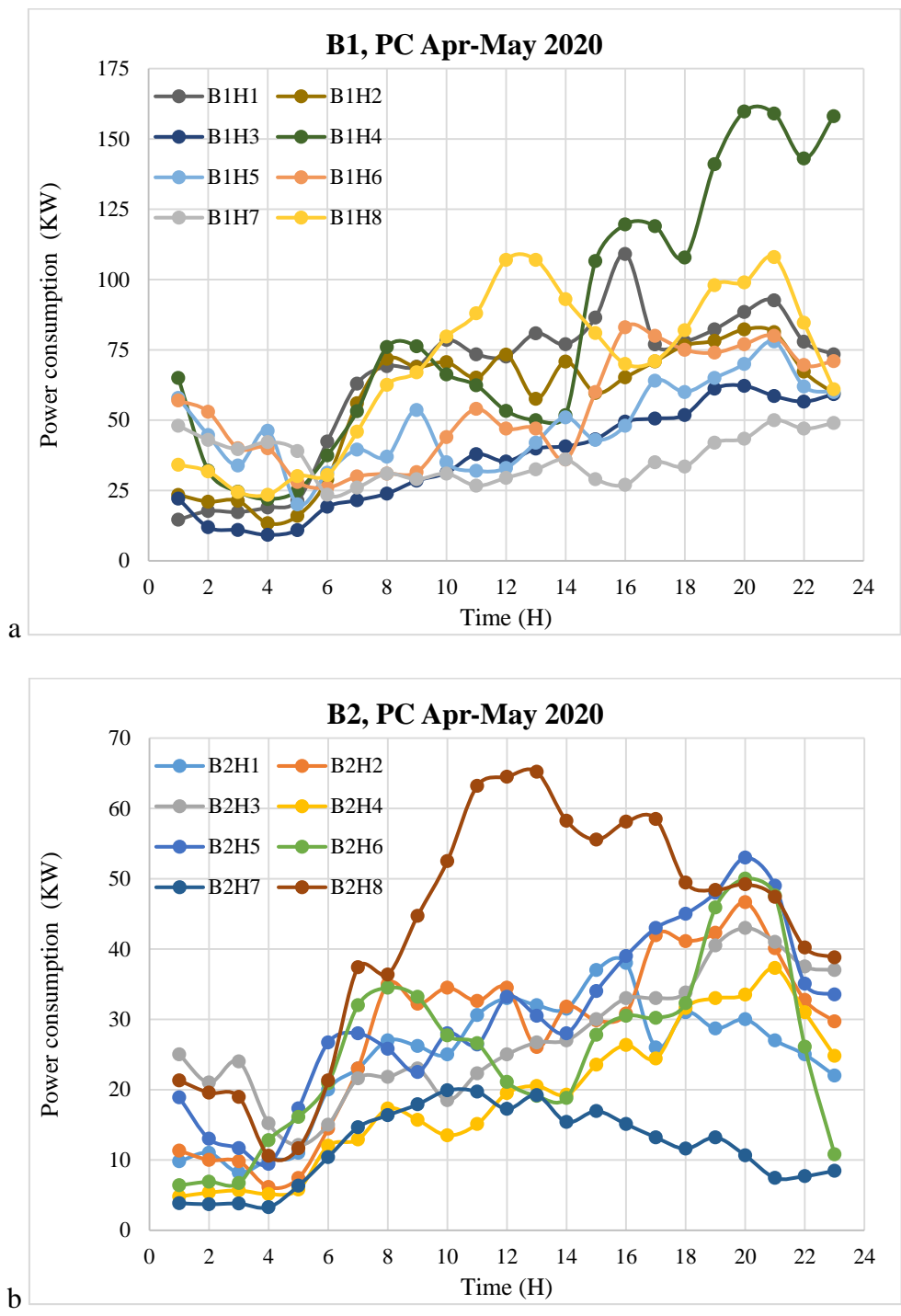


Figure 43 a. and b: Power consumption (EC) for B1 and B2 during April and May 2020, just after Lockdown.

Measurements taken over the period of April and May 2020 for B1 and B2, show that home-based activities were less synchronized and do not follow a monotonous schedule. Actually, during this period in some foyers works were conducted remotely from homes, children studied online and presence of people at their residence led to net increase in the energy use, or other families have left the capital to the villages due to the high risk of COVID19 Contamination in the Capital. Therefore, the increase in the household's electricity needs and the behavior of each block of flats consumption differed depending on the residents' life style, their presence in the flat and their activities.

Before lockdown (March 2020), an identical and typical behavior of energy use is noticeable in both households of the Blocks I and II, where electric energy consumption increases during three time windows that all are considered within the common time of people's presence at their homes.

- The first time slot was identified between 5:00 and 9:00 AM that corresponds to early morning electricity usage before leaving to schools and works.
- The second slot is found between 3:00 and 6:00 PM, a time that matches the returns from schools and the evening assembly of the foyers members.
- The third peak starts at 7:00 and 11:00 PM, where probably individuals perform the missing tasks at home.

The study has been driven for the summer semester of 2020 by taking data of power consumption for B1 and B2 from June 01 to Sept 30, 2020, figure 44 a and b respectively for B1 and B2.

Block 2 belongs to group of families that usually leaves a part of the summer for the vacations while Block 1 residencies remain in the town during the summer.

This survey allowed us to follow the massive consumption during the period of hot weather where people rely intensively on the Air conditioners for cooling, where it can be noticed that foyers of Block 1 have consumed 39067.10 KW compared to 5956.78 KW consumed by the foyers of Block 2, an amount of power consumption for B1 greater by 6.5 times more than the consumption of B2.a

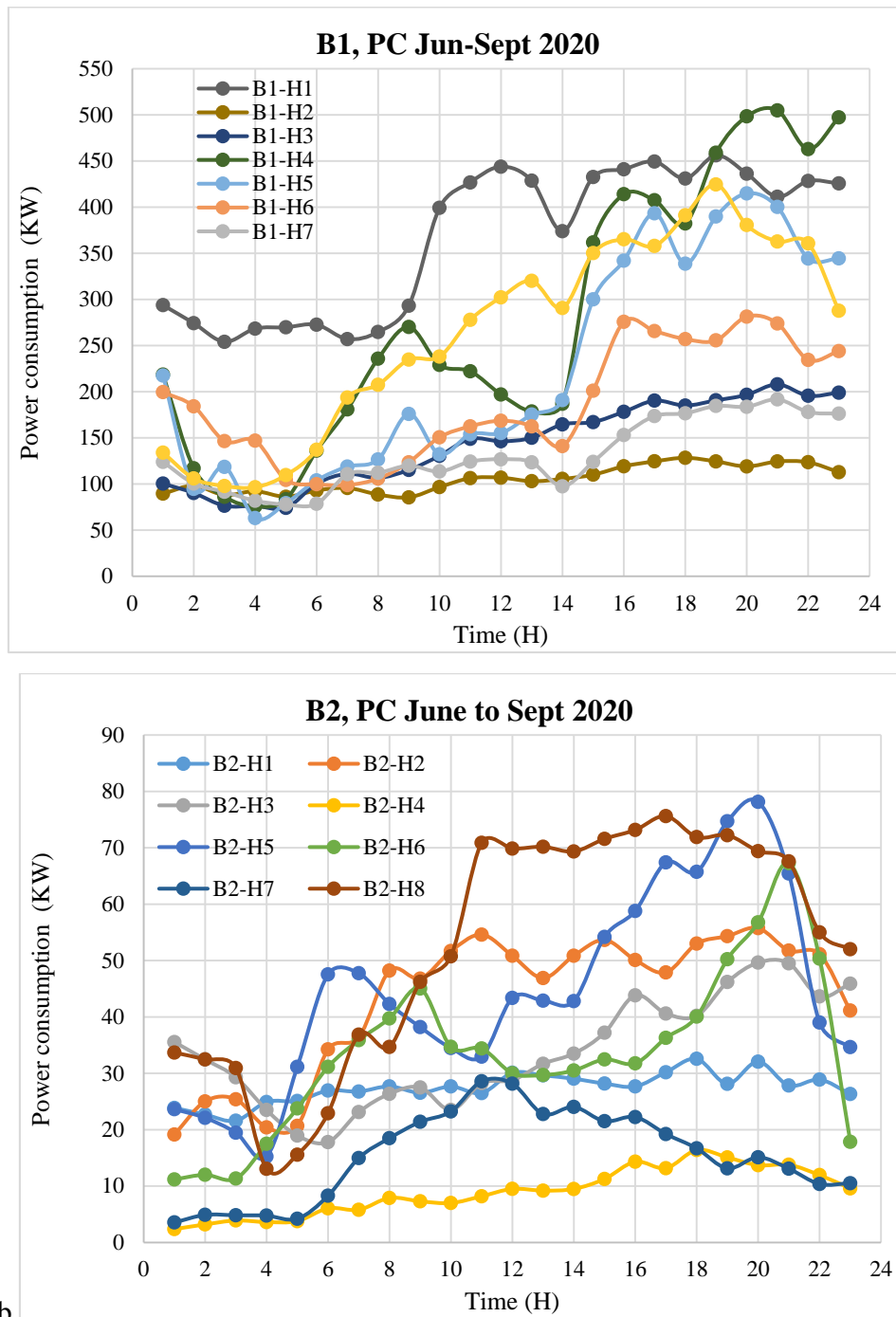
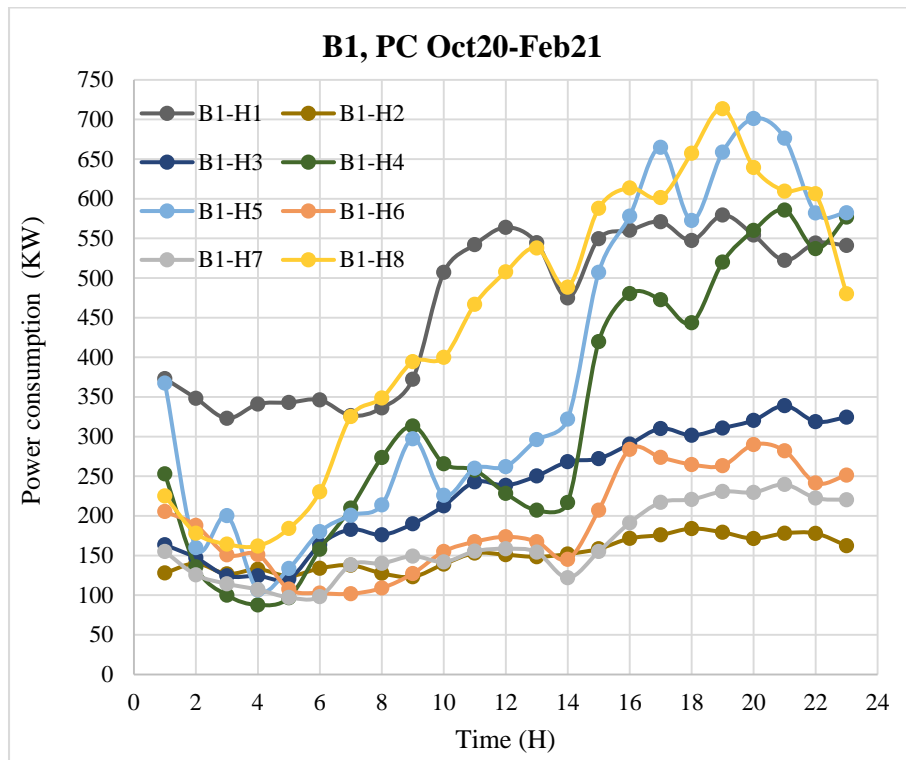
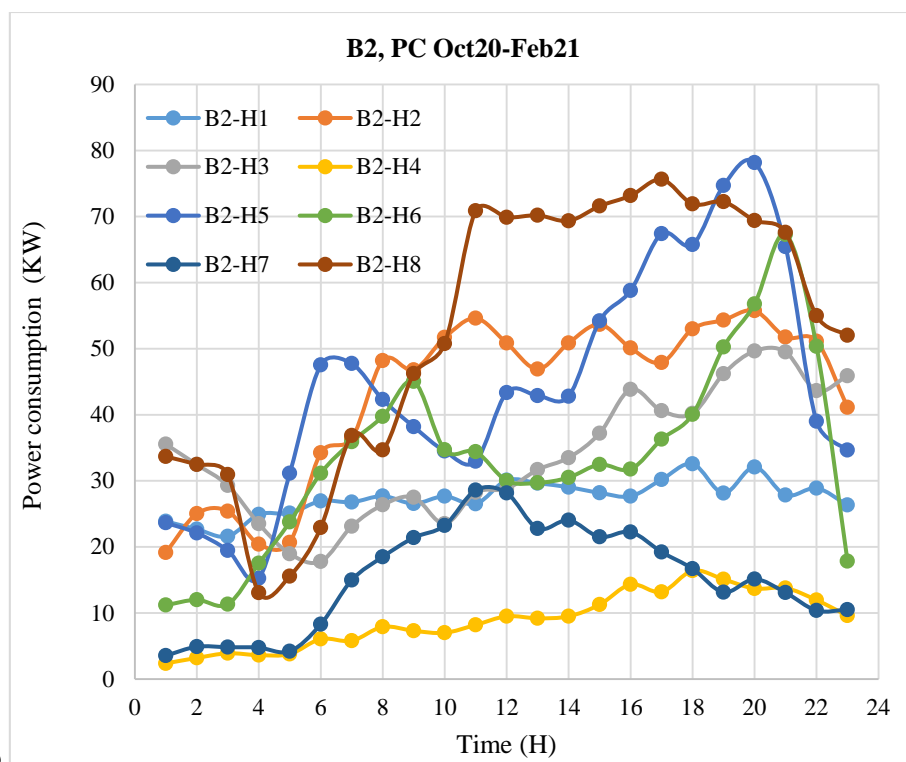


Figure 44 (a) and (b): B1 and B2 Electric power consumption respectively as a function of seasonal hour for the period of June to Sept 2020.

In order to deepen the understanding of the power consumption around all semesters of the year the measurements have continued to cover the period October 2020 to February 2021 that allow us to cover the winter time in our study. Figure 45 a and b give the power consumption respectively for B1 and B2 over the period Oct 2020 to Feb 2021.



a



b

Figure 45 (a) and (b) B1 and B2 Electric power consumption respectively as a function of daytime during summer (Oct 2020 to Feb 2021)

4. 9 Numerical analysis and Micro grid validation as alternative solution for Diesel Generators replacement

Diesel generators (DG) replacement by Micro grid (MG) Energy Management systems (EMS) is proved to have many advantages [56]. To verify this improvement at the level of the total cost that takes into consideration impact on public health, economy and environment a numerical analysis study was realized that allowed us to make a comparison between the cost paid for energy production by DG and MG.

Data input were implemented in a mathematical model that allow an exploration for energy needed for each hour of a day and all data related to the maintenance and consumption according to Diesel generators and Micro-grids system (MGS).

4.9.1 Analytical model development

Notations

H= Horizon = 24 hours

Wi: quantity of energy for every hour over 24 hours, generated arbitrary according random variable

TCMGi = Total cost by using MG at the hour i (i= {1,2,...,24})

TCDi = Total cost by using Diesel generator at the hour i (i= {1,2,...,24})

TCi = Total cost by using Diesel generator or MG at the hour i (i = {1,2,...,24})

$TCi = TCDi \times 1_{Diesel} + TCMGi \times 1_{MG}$

With:

$1_{Diesel} = 1$ if we use Diesel at the hour I and 0 until

$1_{MG} = 1$ if we use MG at the hour I and 0 until

Development of TCDi

$TCDi = ICD + ECDi + CCDi + MCDi$

ICD: Investment cost of Diesel generator/hour = constant

ECDi = environmental cost incurred with using Diesel in the hour i according to the energy wi

CCDi = consumption cost of Diesel generator in the hour i according to the energy wi

MCDi = Maintenance cost of diesel generator in the hour i taking into account maintenance costs, reliability data of Diesel generator and the real energy wi needed

$ICD = UCD / (365 \times 24)$

With: UCD: unit cost of generators used in order to satisfy the Wi needed (cost generator + installation)

$ECDi = (CUO2 \times gd \times LwiD) + ((N \times disp) / (365 \times 24))$

With:

CUO2: unit cost of impact CO2 expressed by mu/TonneCO2

gd: Emission quantity of CO2 incurred by one liter of diesel using Diesel generator

LwiD: Mean Number of patient in hospital by year

N: Mean Number of patient in hospital by year (cause Diesel)

Disp: mean dispense of one patient by year expressed by mu

$$CCDi = Cld \times LwiD$$

With

Cld: unit cost of diesel by liter

LwiD: quantity of liter of diesel needed in order to generate W_i , information from internet net 1 liter de carburant diesel = 40 MJ = 11,1 kWh (you should check)

$$MCDi = (W_i/W_{max}) \times MCD$$

Total cost of maintenance for every i hour taking into account maintenance data failure data and the real energy w_i for every hour

MCD: nominal optimal maintenance cost by /hour is estimated by using other scientific work (Preventive maintenance block type with minimal repair at failure)

Data used and results according to other annex Matlab code

Mcd : unit cost of corrective maintenance for Diesel generator

Mpd: unit cost of corrective maintenance for Diesel generator

Td: optimal preventive maintenance frequency considering as failure law Weibull (shape =2, scale =100) the result is obtained from other Matlab code of maintenance

MCD: Nominal total cost by hour according to M_c , M_p and failure law; the result is obtained from other Matlab code of maintenance

Development of TCMGi

$$TCMGi = ICMG + ECMGi + CCMGi + MCMGi$$

$$ICMG = UCMG / (365 \times 24)$$

With: UCMG: unit cost of MG used in order to satisfy the W_i needed (cost MG + installation...)

$$ECMGi = (CUo2 \times gmg \times W_i) + ((NBR \times RC) / (365 \times 24));$$

With:

CUo2: unit cost of impact CO2 expressed by mu/TCO2

Gmg: emission quantity of CO2 by KW when using MG if it exists and fixed arbitrary if not take $gd=0$

NBR: Number of battery recycled by year if it exists and according the type of MG used

RC: cost of environmental impact of recycling of one battery expressed by mu

$$CCMGi = Clmg \times w_i$$

With:

Clmg: cost KW using MG expressed by mu/KW fixed arbitrary

$$MCMGi = (W_i/W_{max}) \times MCMG$$

Total cost of maintenance for every i hour taking into account maintenance data failure data and the real energy w_i for every hour according to MG

MCMG: nominal optimal maintenance cost by /hour is estimated by using other scientific work (Preventive maintenance block type with minimal repair at failure)

Data used and results according to other annex Matlab code

McMG: unit cost of corrective maintenance for MG

Mpmg: unit cost of corrective maintenance for MG

Tmg: optimal preventive maintenance frequency considering as failure law Weibull (shape =1.3, scale =100) the result is obtained from other Matlab code of maintenance

MCMG: Nominal total cost by hour according to Mc, Mp and failure law; the result is obtained from other Matlab code of maintenance

Decision:

We note by DEC, the decision vector over the horizon H expressed by:

$$DEC = TC_{mgi} - TCD_i;$$

For hours when $DEC > 0$ it is economic to use Diesel generator

For hours when $DEC \leq 0$ it is economic to use Micro grid

The major expenses of Microgrid costs is illustrated in figure 46:

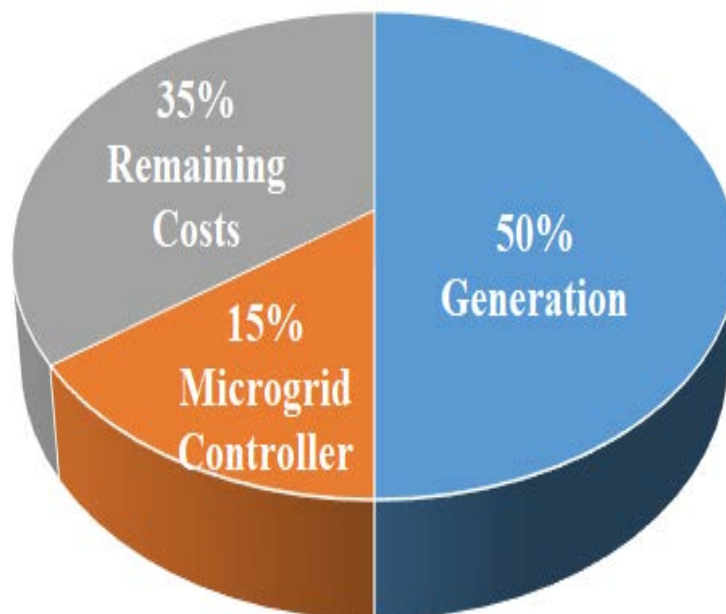


Figure 46: Percentage Distribution for the Investment Cost of a Microgrid

4.9.2 Solving model

By the help of Matlab software we plot the curve of decision according the horizon (24 hours of day for a seasonal hour) and we can easily conclude the periods when it is economic to use Diesel generator corresponding to the hours; when $DEC > 0$ and when it is economic to use Micro grid when $DEC \leq 0$.

Numerical data, results obtained by Numerical Simulation:

Table 1: Numerical Analysis results for Residential B1 for March 2020

B1		Mar, 2020																														
Time H	EC kw B1H1	EC kw B1H2	EC kw B1H3	EC kw B1H4	EC kw B1H5	EC kw B1H6	EC kw B1H7	EC kw B1H8	CS \$ B1H1	CS \$ B1H2	CS \$ B1H3	CS \$ B1H4	CS \$ B1H5	CS \$ B1H6	CS \$ B1H7	CS \$ B1H8	CDP \$ B1H1	CDP \$ B1H2	CDP \$ B1H3	CDP \$ B1H4	CDP \$ B1H5	CDP \$ B1H6	CDP \$ B1H7	CDP \$ B1H8	CMG \$ B1H1	CMG \$ B1H2	CMG \$ B1H3	CMG \$ B1H4	CMG \$ B1H5	CMG \$ B1H6	CMG \$ B1H7	CMG \$ B1H8
1	14.5	13.2	12.0	19.0	19.8	10.9	5.6	14.0	213.8	213.6	213.5	214.3	214.4	213.3	212.7	213.7	214.9	214.7	214.4	215.9	216.0	214.2	213.1	214.8	1.2	1.1	1.0	1.5	1.6	0.9	0.4	1.1
2	17.4	15.8	14.4	22.8	23.8	13.1	6.7	16.8	214.1	213.9	213.8	214.8	214.9	213.6	212.8	214.1	215.5	215.2	214.9	216.6	216.8	214.7	213.4	215.4	1.4	1.3	1.1	1.8	1.9	1.0	0.5	1.3
3	17.4	15.8	14.4	22.8	23.8	13.1	6.7	16.8	214.1	213.9	213.8	214.8	214.9	213.6	212.8	214.1	215.5	215.2	214.9	216.6	216.8	214.7	213.4	215.4	1.4	1.3	1.1	1.8	1.9	1.0	0.5	1.3
4	15.9	14.5	13.2	20.9	21.8	12.0	6.1	15.4	214.0	213.8	213.6	214.6	214.7	213.5	212.8	213.9	215.2	214.9	214.7	216.3	216.4	214.4	213.2	215.1	1.3	1.2	1.1	1.7	1.7	1.0	0.5	1.2
5	18.8	17.1	15.6	24.7	25.8	14.2	7.2	18.2	214.3	214.1	213.9	215.1	215.2	213.8	212.9	214.2	215.8	215.5	215.2	217.0	217.2	214.9	213.5	215.7	1.5	1.4	1.2	2.0	2.1	1.1	0.6	1.5
6	43.4	39.5	35.9	57.0	59.5	32.8	16.7	42.0	217.4	216.9	216.4	219.0	219.3	216.0	214.1	217.2	220.8	220.0	219.3	223.6	224.1	218.7	215.4	220.5	3.5	3.2	2.9	4.6	4.8	2.6	1.3	3.4
7	91.1	82.8	75.4	119.7	124.9	68.8	35.1	88.2	223.3	222.2	221.3	226.8	227.4	220.5	216.3	222.9	230.5	228.9	227.3	236.4	237.4	226.0	219.1	229.9	7.3	6.6	6.0	9.6	10.0	5.5	2.8	7.1
8	89.7	81.5	74.2	117.8	122.9	67.7	34.5	86.8	223.1	222.1	221.2	226.5	227.2	220.4	216.3	222.7	230.2	228.6	227.1	236.0	237.0	225.8	219.0	229.7	7.2	6.5	5.9	9.4	9.8	5.4	2.8	6.9
9	86.8	78.9	71.8	114.0	119.0	65.5	33.4	84.0	222.7	221.7	220.9	226.1	226.7	220.1	216.1	222.4	229.7	228.1	226.6	235.2	236.2	225.3	218.8	229.1	6.9	6.3	5.7	9.1	9.5	5.2	2.7	6.7
10	46.3	42.1	38.3	60.8	63.5	34.9	17.8	44.8	217.7	217.2	216.7	219.5	219.8	216.3	214.2	217.5	221.4	220.6	219.8	224.4	224.9	219.1	215.6	221.1	3.7	3.4	3.1	4.9	5.1	2.8	1.4	3.6
11	43.4	39.5	35.9	57.0	59.5	32.8	16.7	42.0	217.4	216.9	216.4	219.0	219.3	216.0	214.1	217.2	220.8	220.0	219.3	223.6	224.1	218.7	215.4	220.5	3.5	3.2	2.9	4.6	4.8	2.6	1.3	3.4
12	37.6	34.2	31.1	49.4	51.6	28.4	14.5	36.4	216.6	216.2	215.8	218.1	218.4	215.5	213.8	216.5	219.7	219.0	218.3	222.1	222.5	217.8	214.9	219.4	3.0	2.7	2.5	4.0	4.1	2.3	1.2	2.9
13	36.2	32.9	29.9	47.5	49.6	27.3	13.9	35.0	216.5	216.1	215.7	217.9	218.1	215.4	213.7	216.3	219.4	218.7	218.1	221.7	222.1	217.6	214.8	219.1	2.9	2.6	2.4	3.8	4.0	2.2	1.1	2.8
14	39.0	35.5	32.3	51.3	53.5	29.5	15.0	37.8	216.8	216.4	216.0	218.3	218.6	215.6	213.9	216.7	219.9	219.2	218.6	222.4	222.9	218.0	215.1	219.7	3.1	2.8	2.6	4.1	4.3	2.4	1.2	3.0
15	76.6	69.7	63.4	100.7	105.1	57.9	29.5	74.2	221.5	220.6	219.8	224.4	225.0	219.1	215.6	221.2	227.6	226.2	224.9	232.5	233.4	223.8	218.0	227.1	6.1	5.6	5.1	8.1	8.4	4.6	2.4	5.9
16	91.1	82.8	75.4	119.7	124.9	68.8	35.1	88.2	223.3	222.2	221.3	226.8	227.4	220.5	216.3	222.9	230.5	228.9	227.3	236.4	237.4	226.0	219.1	229.9	7.3	6.6	6.0	9.6	10.0	5.5	2.8	7.1
17	85.3	77.6	70.6	112.1	117.0	64.4	32.9	82.6	222.5	221.6	220.7	225.8	226.4	220.0	216.1	222.2	229.4	227.8	226.4	234.8	235.8	225.1	218.7	228.8	6.8	6.2	5.6	9.0	9.4	5.2	2.6	6.6
18	89.7	81.5	74.2	117.8	122.9	67.7	34.5	86.8	223.1	222.1	221.2	226.5	227.2	220.4	216.3	222.7	230.2	228.6	227.1	236.0	237.0	225.8	219.0	229.7	7.2	6.5	5.9	9.4	9.8	5.4	2.8	6.9
19	146.0	132.8	120.9	191.9	200.3	110.3	56.3	141.4	230.0	228.4	226.9	235.7	236.7	225.6	218.9	229.5	241.7	239.0	236.6	251.1	252.8	234.4	223.4	240.8	11.7	10.6	9.7	15.4	16.0	8.8	4.5	11.3
20	147.5	134.1	122.1	193.8	202.3	111.4	56.8	142.8	230.2	228.6	227.1	235.9	237.0	225.8	219.0	229.6	242.0	239.3	236.8	251.4	253.2	234.7	223.6	241.1	11.8	10.7	9.8	15.5	16.2	8.9	4.5	11.4
21	137.4	124.9	113.7	180.5	188.4	103.7	52.9	133.0	229.0	227.4	226.0	234.3	235.3	224.8	218.5	228.4	240.0	237.4	235.1	248.7	250.3	233.1	222.8	239.1	11.0	10.0	9.1	14.4	15.1	8.3	4.2	10.6
22	49.2	44.7	40.7	64.6	67.4	37.1	18.9	47.6	218.1	217.5	217.0	220.0	220.3	216.6	214.3	217.9	222.0	221.1	220.3	225.1	225.7	219.6	215.9	221.7	3.9	3.6	3.3	5.2	5.4	3.0	1.5	3.8
23	26.0	23.7	21.5	34.2	35.7	19.7	10.0	25.2	215.2	214.9	214.7	216.2	216.4	214.4	213.2	215.1	217.3	216.8	216.4	219.0	219.3	216.0	214.0	217.1	2.1	1.9	1.7	2.7	2.9	1.6	0.8	2.0

Total	B1H1	B1H2	B1H3	B1H4	B1H5	B1H6	B1H7	B1H8
EC kw	1446.0	1315.0	1197.0	1900.0	1983.0	1092.0	557.0	1400.0
CD (\$)	289.2	263.0	239.4	380.0	396.6	218.4	111.4	280.0
CDP (\$)	5170.3	5143.6	5119.6	5262.7	5279.5	5098.2	4989.4	5160.9
CMG (\$)	115.7	105.2	95.8	152.0	158.6	87.4	44.6	112.0
CS (\$)	5054.6	5038.4	5023.8	5110.7	5120.9	5010.9	4944.8	5048.9

EC= Energy Consumption; CD = Cost Diesel “Electricity”; CDP= Cost Diesel “Electricity + Pollution” ; CMG = Cost Micro-grid; CS= Cost Saving

Table 2: Numerical Analysis results for Residential B2 for March 2020

Time (H)	B2								Mar, 2020																							
	EC (KW) B2H1	EC (KW) B2H2	EC (KW) B2H3	EC (KW) B2H4	EC (KW) B2H5	EC (KW) B2H6	EC (KW) B2H7	EC (KW) B2H8	CS (\$) B2H1	CS (\$) B2H2	CS (\$) B2H3	CS (\$) B2H4	CS (\$) B2H5	CS (\$) B2H6	CS (\$) B2H7	CS (\$) B2H8	CD (\$) B2H1	CD (\$) B2H2	CD (\$) B2H3	CD (\$) B2H4	CD (\$) B2H5	CD (\$) B2H6	CD (\$) B2H7	CD (\$) B2H8	CMG (\$) B2H1	CMG (\$) B2H2	CMG (\$) B2H3	CMG (\$) B2H4	CMG (\$) B2H5	CMG (\$) B2H6	CMG (\$) B2H7	CMG (\$) B2H8
1.00	3.87	4.95	5.84	4.26	8.34	6.78	3.71	8.34	212.48	212.61	212.72	212.53	213.03	212.84	212.46	213.03	212.79	213.01	213.19	212.87	213.70	213.38	212.75	213.70	0.31	0.40	0.47	0.34	0.67	0.54	0.30	0.67
2.00	4.64	5.94	7.01	5.11	10.01	8.14	4.45	10.01	212.57	212.73	212.87	212.63	213.24	213.00	212.55	213.24	212.95	213.21	213.43	213.04	214.04	213.66	212.91	214.04	0.37	0.48	0.56	0.41	0.80	0.65	0.36	0.80
3.00	4.64	5.94	7.01	5.11	10.01	8.14	4.45	10.01	212.57	212.73	212.87	212.63	213.24	213.00	212.55	213.24	212.95	213.21	213.43	213.04	214.04	213.66	212.91	214.04	0.37	0.48	0.56	0.41	0.80	0.65	0.36	0.80
4.00	4.26	5.45	6.42	4.69	9.17	7.46	4.08	9.17	212.53	212.67	212.79	212.58	213.13	212.92	212.50	213.13	212.87	213.11	213.31	212.95	213.87	213.52	212.83	213.87	0.34	0.44	0.51	0.37	0.73	0.60	0.33	0.73
5.00	5.03	6.44	7.59	5.54	10.84	8.81	4.82	10.84	212.62	212.79	212.94	212.68	213.34	213.09	212.60	213.34	213.02	213.31	213.55	213.13	214.21	213.79	212.98	214.21	0.40	0.51	0.61	0.44	0.87	0.71	0.39	0.87
6.00	11.61	14.85	17.52	12.78	25.02	20.34	11.13	25.02	213.43	213.83	214.16	213.58	215.09	214.51	213.37	215.09	214.36	215.02	215.57	214.60	217.09	216.14	214.26	217.09	0.93	1.19	1.40	1.02	2.00	1.63	0.89	2.00
7.00	24.38	31.19	36.79	26.84	52.54	42.71	23.37	52.54	215.01	215.85	216.54	215.31	218.49	217.28	214.89	218.49	216.96	218.35	219.49	217.46	222.69	220.69	216.76	222.69	1.95	2.49	2.94	2.15	4.20	3.42	1.87	4.20
8.00	23.99	30.69	36.21	26.41	51.71	42.04	23.00	51.71	214.96	215.79	216.47	215.26	218.39	217.19	214.84	218.39	216.88	218.25	219.37	217.37	222.52	220.55	216.68	222.52	1.92	2.46	2.90	2.11	4.14	3.36	1.84	4.14
9.00	23.22	29.70	35.04	25.56	50.04	40.68	22.26	50.04	214.87	215.67	216.33	215.16	218.18	217.02	214.75	218.18	216.73	218.04	219.13	217.20	222.18	220.28	216.53	222.18	1.86	2.38	2.80	2.04	4.00	3.25	1.78	4.00
10.00	12.38	15.84	18.69	13.63	26.69	21.70	11.87	26.69	213.53	213.96	214.31	213.68	215.30	214.68	213.47	215.30	214.52	215.22	215.80	214.77	217.43	216.42	214.42	217.43	0.99	1.27	1.50	1.09	2.14	1.74	0.95	2.14
11.00	11.61	14.85	17.52	12.78	25.02	20.34	11.13	25.02	213.43	213.83	214.16	213.58	215.09	214.51	213.37	215.09	214.36	215.02	215.57	214.60	217.09	216.14	214.26	217.09	0.93	1.19	1.40	1.02	2.00	1.63	0.89	2.00
12.00	10.06	12.87	15.18	11.08	21.68	17.63	9.65	21.68	213.24	213.59	213.88	213.37	214.68	214.18	213.19	214.68	214.05	214.62	215.09	214.25	216.41	215.59	213.96	216.41	0.80	1.03	1.21	0.89	1.73	1.41	0.77	1.73
13.00	9.68	12.38	14.60	10.65	20.85	16.95	9.28	20.85	213.19	213.53	213.80	213.32	214.58	214.09	213.15	214.58	213.97	214.52	214.97	214.17	216.24	215.45	213.89	216.24	0.77	0.99	1.17	0.85	1.67	1.36	0.74	1.67
14.00	10.45	13.37	15.77	11.50	22.52	18.31	10.02	22.52	213.29	213.65	213.95	213.42	214.78	214.26	213.24	214.78	214.13	214.72	215.21	214.34	216.58	215.73	214.04	216.58	0.84	1.07	1.26	0.92	1.80	1.46	0.80	1.80
15.00	20.51	26.24	30.95	22.58	44.20	35.93	19.66	44.20	214.53	215.24	215.82	214.79	217.46	216.44	214.43	217.46	216.17	217.34	218.30	216.59	221.00	219.31	216.00	221.00	1.64	2.10	2.48	1.81	3.54	2.87	1.57	3.54
16.00	24.38	31.19	36.79	26.84	52.54	42.71	23.37	52.54	215.01	215.85	216.54	215.31	218.49	217.28	214.89	218.49	216.96	218.35	219.49	217.46	222.69	220.69	216.76	222.69	1.95	2.49	2.94	2.15	4.20	3.42	1.87	4.20
17.00	22.83	29.21	34.46	25.13	49.21	40.00	21.89	49.21	214.82	215.61	216.26	215.10	218.08	216.94	214.70	218.08	216.65	217.94	219.01	217.11	222.01	220.14	216.45	222.01	1.83	2.34	2.76	2.01	3.94	3.20	1.75	3.94
18.00	23.99	30.69	36.21	26.41	51.71	42.04	23.00	51.71	214.96	215.79	216.47	215.26	218.39	217.19	214.84	218.39	216.88	218.25	219.37	217.37	222.52	220.55	216.68	222.52	1.92	2.46	2.90	2.11	4.14	3.36	1.84	4.14
19.00	39.09	50.00	58.99	43.03	84.24	68.48	37.47	84.24	216.83	218.17	219.28	217.31	222.40	220.46	216.63	222.40	219.95	222.17	224.00	220.76	229.14	225.94	219.63	229.14	3.13	4.00	4.72	3.44	6.74	5.48	3.00	6.74
20.00	39.47	50.49	59.57	43.45	85.07	69.16	37.84	85.07	216.88	218.24	219.36	217.37	222.51	220.54	216.67	222.51	220.03	222.27	224.12	220.84	229.31	226.07	219.70	229.31	3.16	4.04	4.77	3.48	6.81	5.53	3.03	6.81
21.00	36.77	47.03	55.48	40.47	79.23	64.41	35.25	79.23	216.54	217.81	218.85	217.00	221.79	219.95	216.35	221.79	219.48	221.57	223.29	220.24	228.12	225.11	219.17	228.12	2.94	3.76	4.44	3.24	6.34	5.15	2.82	6.34
22.00	13.16	16.83	19.86	14.48	28.36	23.05	12.61	28.36	213.63	214.08	214.45	213.79	215.50	214.85	213.56	215.50	214.68	215.42	216.04	214.95	217.77	216.69	214.57	217.77	1.05	1.35	1.59	1.16	2.27	1.84	1.01	2.27
23.00	6.97	8.91	10.51	7.67	15.01	12.20	6.68	15.01	212.86	213.10	213.30	212.95	213.85	213.51	212.82	213.85	213.42	213.81	214.14	213.56	215.05	214.48	213.36	215.06	0.56	0.71	0.84	0.61	1.20	0.98	0.53	1.20

Total	B2H1	B2H2	B2H3	B2H4	B2H5	B2H6	B2H7	B2H8
EC (KW)	387	495	584	426	834	678	371	834
CD (\$)	77	99	117	85	167	136	74	167
CDP (\$)	4955	4977	4995	4963	5046	5014	4951	5046
CMG (S)	31	40	47	34	67	54	30	67
CS (S)	4924	4937	4948	4929	4979	4960	4922	4979

Table 3: Numerical Analysis results for Residential B1 for April-May 2020

Time (H)	EC kw								CS (\$)								CDP (\$)								CMG (\$)							
	B1H1	B1H2	B1H3	B1H4	B1H5	B1H6	B1H7	B1H8	B1H1	B1H2	B1H3	B1H4	B1H5	B1H6	B1H7	B1H8	B1H1	B1H2	B1H3	B1H4	B1H5	B1H6	B1H7	B1H8	B1H1	B1H2	B1H3	B1H4	B1H5	B1H6	B1H7	B1H8
1	14.6	23.4	22.1	65.0	57.9	57.0	48.0	34.2	213.8	214.9	214.7	220.0	219.2	219.0	217.9	216.2	215.0	216.8	216.5	225.2	223.8	223.6	221.8	219.0	1.2	1.9	1.8	5.2	4.6	4.6	3.8	2.7
2	17.7	21.0	11.9	32.1	44.7	53.0	43.0	31.8	214.2	214.6	213.5	216.0	217.5	218.5	217.3	215.9	215.6	216.3	214.4	218.5	221.1	222.8	220.8	218.5	1.4	1.7	1.0	2.6	3.6	4.2	3.4	2.5
3	17.3	21.3	10.9	24.6	33.9	40.0	39.7	24.4	214.1	214.6	213.4	215.0	216.2	216.9	216.9	215.0	215.5	216.3	214.2	217.0	218.9	220.1	220.1	217.0	1.4	1.7	0.9	2.0	2.7	3.2	3.2	2.0
4	18.9	13.4	9.2	21.9	46.2	40.0	42.2	23.5	214.3	213.7	213.1	214.7	217.7	216.9	217.2	214.9	215.9	214.7	213.9	216.5	221.4	220.1	220.6	216.8	1.5	1.1	0.7	1.8	3.7	3.2	3.4	1.9
5	21.4	16.0	10.9	24.9	20.1	28.0	39.0	30.1	214.6	214.0	213.3	215.1	214.5	215.5	216.8	215.7	216.4	215.3	214.2	217.1	216.1	217.7	219.9	218.1	1.7	1.3	0.9	2.0	1.6	2.2	3.1	2.4
6	42.4	28.9	19.2	37.5	31.3	26.0	23.5	30.5	217.2	215.6	214.4	216.6	215.9	215.2	214.9	215.8	220.6	217.9	215.9	219.6	218.4	217.3	216.8	218.2	3.4	2.3	1.5	3.0	2.5	2.1	1.9	2.4
7	63.0	56.0	21.5	53.2	39.5	30.0	26.0	45.9	219.8	218.9	214.7	218.6	216.9	215.7	215.2	217.7	224.8	223.4	216.4	222.8	220.0	218.1	217.3	221.3	5.0	4.5	1.7	4.3	3.2	2.4	2.1	3.7
8	69.2	71.8	23.9	76.0	37.0	31.0	31.0	62.6	220.5	220.9	215.0	221.4	216.6	215.8	215.8	219.7	226.1	226.6	216.9	227.5	219.5	218.3	218.3	224.7	5.5	5.7	1.9	6.1	3.0	2.5	2.5	5.0
9	69.0	68.9	28.5	76.3	53.6	31.5	29.0	67.0	220.5	220.5	215.5	221.4	218.6	215.9	215.6	220.3	226.0	226.0	217.8	227.5	222.9	218.4	217.9	225.6	5.5	5.5	2.3	6.1	4.3	2.5	2.3	5.4
10	78.5	70.6	31.3	66.3	35.0	44.0	31.0	79.7	221.7	220.7	215.9	220.2	216.3	217.4	215.8	221.8	228.0	226.4	218.4	225.5	219.1	221.0	218.3	228.2	6.3	5.6	2.5	5.3	2.8	3.5	2.5	6.4
11	73.4	65.1	37.9	62.4	32.0	54.0	26.7	88.0	221.1	220.0	216.7	219.7	216.0	218.7	215.3	222.9	226.9	225.2	219.7	224.7	218.5	223.0	217.4	229.9	5.9	5.2	3.0	5.0	2.6	4.3	2.1	7.0
12	72.6	73.3	35.3	53.3	33.0	47.0	29.5	107.0	221.0	221.1	216.4	218.6	216.1	217.8	215.6	225.2	226.8	226.9	219.2	222.8	218.7	221.6	218.0	233.8	5.8	5.9	2.8	4.3	2.6	3.8	2.4	8.6
13	80.9	57.6	39.9	50.0	42.0	47.0	32.5	107.0	222.0	219.1	216.9	218.2	217.2	217.8	216.0	225.2	228.5	223.7	220.1	222.2	220.5	221.6	218.6	233.8	6.5	4.6	3.2	4.0	3.4	3.8	2.6	8.6
14	77.0	70.8	40.7	51.8	51.0	36.0	36.0	93.0	221.5	220.7	217.0	218.4	218.3	216.4	216.4	223.5	227.7	226.4	220.3	222.5	222.4	219.3	219.3	230.9	6.2	5.7	3.3	4.1	4.1	2.9	2.9	7.4
15	86.5	59.7	43.2	106.6	43.0	60.0	29.0	81.0	222.7	219.4	217.3	225.2	217.3	219.4	215.6	222.0	229.6	224.1	220.8	233.7	220.8	224.2	217.9	228.5	6.9	4.8	3.5	8.5	3.4	4.8	2.3	6.5
16	109.1	65.2	49.5	119.6	48.0	83.0	27.0	70.0	225.5	220.1	218.1	226.8	217.9	222.3	215.3	220.6	234.2	225.3	222.1	236.3	221.8	228.9	217.5	226.2	8.7	5.2	4.0	9.6	3.8	6.6	2.2	5.6
17	77.0	70.9	50.6	119.0	64.0	80.0	35.0	71.0	221.5	220.8	218.2	226.7	219.9	221.9	216.3	220.8	227.7	226.4	222.3	236.2	225.0	228.3	219.1	226.4	6.2	5.7	4.0	9.5	5.1	6.4	2.8	5.7
18	77.9	76.6	51.8	107.8	60.0	75.0	33.5	82.0	221.6	221.5	218.4	225.3	219.4	221.3	216.1	222.1	227.9	227.6	222.6	233.9	224.2	227.3	218.8	228.7	6.2	6.1	4.1	8.6	4.8	6.0	2.7	6.6
19	82.3	78.2	61.2	141.0	65.0	74.0	42.0	98.0	222.2	221.7	219.6	229.4	220.0	221.1	217.2	224.1	228.7	227.9	224.5	240.7	225.2	227.1	220.5	231.9	6.6	6.3	4.9	11.3	5.2	5.9	3.4	7.8
20	88.5	82.3	62.2	159.8	70.0	77.0	43.4	99.0	222.9	222.2	219.7	231.7	220.6	221.5	217.4	224.2	230.0	228.7	224.7	244.5	226.2	227.7	220.8	232.1	7.1	6.6	5.0	12.8	5.6	6.2	3.5	7.9
21	92.6	81.3	58.6	159.0	78.0	80.0	50.0	108.0	223.4	222.0	219.2	231.6	221.6	221.9	218.2	225.3	230.8	228.5	223.9	244.4	227.9	228.3	222.2	234.0	7.4	6.5	4.7	12.7	6.2	6.4	4.0	8.6
22	77.9	67.3	56.6	143.1	62.0	69.6	47.0	84.7	221.6	220.3	219.0	229.7	219.7	220.6	217.8	222.5	227.9	225.7	223.5	241.1	224.6	226.2	221.6	229.2	6.2	5.4	4.5	11.4	5.0	5.6	3.8	6.8
23	73.4	59.5	59.3	158.1	60.0	71.0	49.0	61.0	221.1	219.3	219.3	231.5	219.4	220.8	218.1	219.5	226.9	224.1	224.1	244.2	224.2	226.4	222.0	224.4	5.9	4.8	4.7	12.6	4.8	5.7	3.9	4.9

Total	B1H1	B1H2	B1H3	B1H4	B1H5	B1H6	B1H7	B1H8
EC kw	1481.0	1299.1	836.3	1909.0	1107.2	1234.1	833.0	1579.3
CD (\$)	296.2	259.8	167.3	381.8	221.4	246.8	166.6	315.9
CDP (\$)	5177.4	5140.4	5046.2	5264.5	5101.3	5127.1	5045.5	5197.4
CMG (\$)	118.5	103.9	66.9	152.7	88.6	98.7	66.6	126.3
CS (\$)	5058.9	5036.4	4979.3	5111.8	5012.7	5028.4	4978.9	5071.0

Table 4: Numerical Analysis results for Residential B2 for April-May 2020

Time (H)	EC (KW)								CS (\$)								CD (\$)								CMG (\$)							
	B2H1	B2H2	B2H3	B2H4	B2H5	B2H6	B2H7	B2H8	B2H1	B2H2	B2H3	B2H4	B2H5	B2H6	B2H7	B2H8	B2H1	B2H2	B2H3	B2H4	B2H5	B2H6	B2H7	B2H8	B2H1	B2H2	B2H3	B2H4	B2H5	B2H6	B2H7	B2H8
1.00	9.80	11.32	25.00	4.80	18.90	6.40	3.85	21.30	213.21	213.40	215.09	212.59	214.33	212.79	212.48	214.63	213.99	214.30	217.09	212.98	215.85	213.30	212.78	216.33	0.78	0.91	2.00	0.38	1.51	0.51	0.31	1.70
2.00	11.00	10.00	21.00	5.36	13.00	6.90	3.70	19.56	213.36	213.24	214.59	212.66	213.61	212.85	212.46	214.42	214.24	214.04	216.27	213.09	214.65	213.40	212.75	215.98	0.88	0.80	1.68	0.43	1.04	0.55	0.30	1.56
3.00	8.20	9.80	24.00	5.66	11.68	6.70	3.80	18.96	213.01	213.21	214.96	212.70	213.44	212.83	212.47	214.34	213.67	213.99	216.88	213.15	214.38	213.36	212.77	215.86	0.66	0.78	1.92	0.45	0.93	0.54	0.30	1.52
4.00	10.00	6.15	15.20	5.13	9.44	12.80	3.28	10.58	213.24	212.76	213.88	212.63	213.17	213.58	212.40	213.31	214.04	213.25	215.09	213.04	213.92	214.60	212.67	214.15	0.80	0.49	1.22	0.41	0.76	1.02	0.26	0.85
5.00	11.00	7.43	12.10	5.79	17.32	16.10	6.33	11.64	213.36	212.92	213.49	212.72	214.14	213.99	212.78	213.44	214.24	213.51	214.46	213.18	215.52	215.28	213.29	214.37	0.88	0.59	0.97	0.46	1.39	1.29	0.51	0.93
6.00	20.00	14.45	15.00	12.00	26.70	20.90	10.40	21.30	214.47	213.78	213.85	213.48	215.30	214.58	213.28	214.63	216.07	214.94	215.05	214.44	217.43	216.25	214.12	216.33	1.60	1.16	1.20	0.96	2.14	1.67	0.83	1.70
7.00	23.00	23.00	21.60	12.90	28.00	32.00	14.65	37.40	214.84	214.84	214.67	213.59	215.46	215.95	213.81	216.62	216.68	216.68	216.40	214.63	217.70	218.51	214.98	219.61	1.84	1.84	1.73	1.03	2.24	2.56	1.17	2.99
8.00	27.00	35.00	21.80	17.30	25.80	34.50	16.35	36.36	215.33	216.32	214.69	214.14	215.19	216.26	214.02	216.49	217.49	219.12	216.44	215.52	217.25	219.02	215.33	219.40	2.16	2.80	1.74	1.38	2.06	2.76	1.31	2.91
9.00	26.20	32.20	23.00	15.70	22.50	33.20	17.90	44.70	215.24	215.98	214.84	213.94	214.78	216.10	214.21	217.52	217.33	218.55	216.68	215.19	216.58	218.76	215.64	221.10	2.10	2.58	1.84	1.26	1.80	2.66	1.43	3.58
10.00	25.00	34.50	18.50	13.50	28.00	27.70	19.90	52.50	215.09	216.26	214.28	213.67	215.46	215.42	214.46	218.48	217.09	219.02	215.76	214.75	217.70	217.64	216.05	222.68	2.00	2.76	1.48	1.08	2.24	2.22	1.59	4.20
11.00	30.60	32.60	22.30	15.10	26.40	26.60	19.70	63.20	215.78	216.03	214.75	213.86	215.26	215.29	214.43	219.81	218.23	218.63	216.54	215.07	217.37	217.41	216.01	224.86	2.45	2.61	1.78	1.21	2.11	2.13	1.58	5.06
12.00	33.00	34.50	25.00	19.50	33.20	21.10	17.25	64.50	216.08	216.26	215.09	214.41	216.10	214.61	214.13	219.97	218.72	219.02	217.09	215.97	218.76	216.29	215.51	225.13	2.64	2.76	2.00	1.56	2.66	1.69	1.38	5.16
13.00	32.00	26.05	26.70	20.50	30.50	19.10	19.20	65.20	215.95	215.22	215.30	214.53	215.77	214.36	214.37	220.05	218.51	217.30	217.43	216.17	218.21	215.89	215.91	225.27	2.56	2.08	2.14	1.64	2.44	1.53	1.54	5.22
14.00	31.50	31.80	27.00	19.26	28.00	18.80	15.40	58.24	215.89	215.93	215.33	214.38	215.46	214.32	213.90	219.19	218.41	218.47	217.49	215.92	217.70	215.83	215.13	223.85	2.52	2.54	2.16	1.54	2.24	1.50	1.23	4.66
15.00	37.00	29.85	30.00	23.54	34.00	27.80	16.95	55.56	216.57	215.69	215.71	214.91	216.20	215.43	214.09	218.86	219.53	218.07	218.11	216.79	218.92	217.66	215.45	223.31	2.96	2.39	2.40	1.88	2.72	2.22	1.36	4.44
16.00	38.00	30.80	33.00	26.34	39.00	30.50	15.10	58.10	216.69	215.80	216.08	215.25	216.82	215.77	213.86	219.18	219.73	218.27	218.72	217.36	219.94	218.21	215.07	223.82	3.04	2.46	2.64	2.11	3.12	2.44	1.21	4.65
17.00	26.00	41.95	33.00	24.42	43.00	30.20	13.20	58.48	215.21	217.18	216.08	215.02	217.31	215.73	213.63	219.22	217.29	220.54	218.72	216.97	220.75	218.15	214.69	223.90	2.08	3.36	2.64	1.95	3.44	2.42	1.06	4.68
18.00	31.00	41.10	33.80	31.60	45.00	32.30	11.60	49.44	215.83	217.08	216.17	215.90	217.56	215.99	213.43	218.11	218.31	220.36	218.88	218.43	221.16	218.57	214.36	222.06	2.48	3.29	2.70	2.53	3.60	2.58	0.93	3.96
19.00	28.70	42.30	40.50	33.00	48.00	45.90	13.20	48.40	215.54	217.22	217.00	216.08	217.93	217.67	213.63	217.98	217.84	220.61	220.24	218.72	221.77	221.34	214.69	221.85	2.30	3.38	3.24	2.64	3.84	3.67	1.06	3.87
20.00	30.00	46.65	43.00	33.50	53.00	50.00	10.65	49.20	215.71	217.76	217.31	216.14	218.55	218.18	213.32	218.08	218.11	221.49	220.75	218.82	222.79	222.18	214.17	222.01	2.40	3.73	3.44	2.68	4.24	4.00	0.85	3.94
21.00	27.00	40.10	41.00	37.30	49.00	47.60	7.45	47.40	215.33	216.95	217.06	216.61	218.05	217.88	212.92	217.85	217.49	220.16	220.34	219.59	221.97	221.69	213.52	221.65	2.16	3.21	3.28	2.98	3.92	3.81	0.60	3.79
22.00	25.00	32.75	37.50	31.00	35.06	26.10	7.70	40.20	215.09	216.04	216.63	215.83	216.33	215.22	212.95	216.96	217.09	218.66	219.63	218.31	219.13	217.31	213.57	220.18	2.00	2.62	3.00	2.48	2.80	2.09	0.62	3.22
23.00	22.00	29.70	37.00	24.80	33.52	10.80	8.45	38.80	214.72	215.67	216.57	215.06	216.14	213.33	213.04	216.79	216.48	218.04	219.53	217.05	218.82	214.20	213.72	219.90	1.76	2.38	2.96	1.98	2.68	0.86	0.68	3.10

Total	B2H1	B2H2	B2H3	B2H4	B2H5	B2H6	B2H7	B2H8
EC (KW)	563	644	627	438	699	584	276	971
CD (\$)	113	129	125	88	140	117	55	194
CDP (\$)	4991	5007	5004	4965	5018	4995	4932	5074
CMG (\$)	45	52	50	35	56	47	22	78
CS (\$)	4946	4956	4953	4930	4962	4948	4910	4996

Table 5: Numerical Analysis results for Residential B1 for June-September 2020

Time (H)	Jun-Sept 2020																															
	EC kw B1H1	EC kw B1H2	EC kw B1H3	EC kw B1H4	EC kw B1H5	EC kw B1H6	EC kw B1H7	EC kw B1H8	CS (\$) B1H1	CS (\$) B1H2	CS (\$) B1H3	CS (\$) B1H4	CS (\$) B1H5	CS (\$) B1H6	CS (\$) B1H7	CS (\$) B1H8	CDP (\$) B1H1	CDP (\$) B1H2	CDP (\$) B1H3	CDP (\$) B1H4	CDP (\$) B1H5	CDP (\$) B1H6	CDP (\$) B1H7	CDP (\$) B1H8	CMG (\$) B1H1	CMG (\$) B1H2	CMG (\$) B1H3	CMG (\$) B1H4	CMG (\$) B1H5	CMG (\$) B1H6	CMG (\$) B1H7	CMG (\$) B1H8
1	293.8	89.5	100.4	218.6	217.4	199.5	124.0	133.9	302.1	250.8	253.5	283.2	282.9	278.4	259.5	262.0	325.6	258.0	261.6	300.7	300.3	294.4	269.4	272.7	23.5	7.2	8.0	17.5	17.4	16.0	9.9	10.7
2	274.3	98.1	90.3	117.0	94.6	184.1	100.4	105.9	297.2	253.0	251.0	257.7	252.1	274.5	253.5	254.9	319.1	260.8	258.2	267.1	259.6	289.3	261.6	263.4	21.9	7.9	7.2	9.4	7.6	14.7	8.0	8.5
3	254.1	88.0	76.3	86.2	118.5	146.5	91.5	97.8	292.1	250.4	247.5	250.0	258.1	265.1	251.3	252.9	312.5	257.5	253.6	256.8	267.6	276.8	258.6	260.7	20.3	7.0	6.1	6.9	9.5	11.7	7.3	7.8
4	268.4	92.2	76.3	75.6	63.0	146.9	81.8	96.4	295.7	251.5	247.5	247.3	244.1	265.2	248.9	252.5	317.2	258.8	253.6	253.3	249.2	277.0	255.4	260.2	21.5	7.4	6.1	6.0	5.0	11.8	6.6	7.7
5	269.8	86.1	74.0	83.5	79.1	104.4	77.7	109.6	296.1	249.9	246.9	249.3	248.2	254.5	247.8	255.8	317.7	256.8	252.8	256.0	254.5	262.9	254.0	264.6	21.6	6.9	5.9	6.7	6.3	8.4	6.2	8.8
6	272.6	93.0	100.3	136.1	103.9	99.7	78.5	137.1	296.8	251.7	253.5	262.5	254.4	253.3	248.0	262.8	318.6	259.1	261.5	273.4	262.7	261.3	254.3	273.7	21.8	7.4	8.0	10.9	8.3	8.0	6.3	11.0
7	257.1	95.7	111.0	180.8	118.8	98.8	110.7	193.7	292.9	252.3	256.2	273.7	258.1	253.1	256.1	277.0	313.5	260.0	265.1	288.2	267.6	261.0	265.0	292.4	20.6	7.7	8.9	14.5	9.5	7.9	8.9	15.5
8	264.7	88.6	106.5	235.8	126.6	105.8	112.1	207.5	294.8	250.5	255.1	287.5	260.1	254.9	256.5	280.4	316.0	257.6	263.6	306.4	270.2	263.3	265.4	297.0	21.2	7.1	8.5	18.9	10.1	8.5	9.0	16.6
9	293.2	85.5	115.3	270.1	175.9	123.5	119.8	234.8	302.0	249.8	257.3	296.2	272.5	259.3	258.4	287.3	325.4	256.6	266.5	317.8	286.6	269.2	268.0	306.1	23.5	6.8	9.2	21.6	14.1	9.9	9.6	18.8
10	399.3	96.6	130.5	229.1	132.1	150.6	113.5	238.0	328.6	252.6	261.1	285.8	261.5	266.1	256.8	288.1	360.6	260.3	271.5	304.2	272.1	278.2	265.9	307.1	32.0	7.7	10.4	18.3	10.6	12.1	9.1	19.0
11	426.8	106.3	149.0	222.2	153.8	162.4	124.3	277.9	335.5	255.0	265.7	284.1	266.9	269.1	259.5	298.1	369.7	263.5	277.7	301.9	279.3	282.1	269.5	320.3	34.2	8.5	11.9	17.8	12.3	13.0	9.9	22.2
12	444.0	106.9	146.3	196.9	155.1	168.5	126.7	302.2	339.8	255.1	265.0	277.8	267.3	270.6	260.1	304.2	375.3	263.7	276.8	293.5	279.7	284.1	270.3	328.4	35.5	8.6	11.7	15.8	12.4	13.5	10.1	24.2
13	428.7	103.0	150.0	178.5	175.2	162.5	123.3	320.2	336.0	254.2	266.0	273.1	272.3	269.1	259.3	308.7	370.3	262.4	278.0	287.4	286.3	282.1	269.2	334.3	34.3	8.2	12.0	14.3	14.0	13.0	9.9	25.6
14	373.9	105.4	164.6	187.0	190.9	141.0	97.5	290.7	322.2	254.8	269.7	275.3	276.3	263.7	252.8	301.3	352.2	263.2	282.8	290.2	291.5	275.0	260.6	324.6	29.9	8.4	13.2	15.0	15.3	11.3	7.8	23.3
15	432.7	110.0	167.0	361.8	300.0	201.1	124.0	350.3	337.0	255.9	270.3	319.2	303.7	278.8	259.4	316.3	371.6	264.7	283.6	348.1	327.7	294.9	269.4	344.3	34.6	8.8	13.4	29.0	24.0	16.1	9.9	28.0
16	441.1	119.2	178.2	414.0	342.1	275.7	153.0	365.2	339.1	258.2	273.1	332.3	314.2	297.6	266.7	320.1	374.4	267.8	287.3	365.4	341.6	319.6	279.0	349.3	35.3	9.5	14.3	33.1	27.4	22.1	12.2	29.2
17	449.5	124.5	190.3	407.4	393.4	265.7	173.6	358.0	341.2	259.6	276.1	330.7	327.1	295.1	271.9	318.2	377.2	269.5	291.3	363.3	358.6	316.3	285.8	346.9	36.0	10.0	15.2	32.6	31.5	21.3	13.9	28.6
18	431.0	128.4	185.0	382.3	338.8	257.1	176.5	391.3	336.6	260.6	274.8	324.3	313.4	292.9	272.6	326.6	371.1	270.8	289.6	354.9	340.5	313.4	286.8	357.9	34.5	10.3	14.8	30.6	27.1	20.6	14.1	31.3
19	456.2	124.5	190.6	459.0	389.9	255.6	184.6	424.7	342.9	259.6	276.2	343.6	326.2	292.5	274.7	335.0	379.4	269.5	291.4	380.3	357.4	313.0	289.4	369.0	36.5	10.0	15.3	36.7	31.2	20.5	14.8	34.0
20	436.3	119.0	196.6	498.4	414.9	281.4	183.7	380.6	337.9	258.2	277.7	353.5	332.5	299.0	274.4	323.9	372.8	267.7	293.4	393.4	365.7	321.5	289.1	354.4	34.9	9.5	15.7	39.9	33.2	22.5	14.7	30.5
21	411.2	124.4	208.0	504.9	400.2	273.9	191.7	362.8	331.6	259.5	280.6	355.1	328.8	297.1	276.5	319.4	364.5	269.5	297.2	395.5	360.9	319.0	291.8	348.5	32.9	10.0	16.6	40.4	32.0	21.9	15.3	29.0
22	428.4	123.6	195.6	462.9	344.4	234.5	178.0	360.8	335.9	259.3	277.4	344.6	314.8	287.2	273.0	318.9	370.2	269.2	293.1	381.6	342.4	306.0	287.3	347.8	34.3	9.9	15.7	37.0	27.6	18.8	14.2	28.9
23	425.9	112.8	199.0	497.3	344.5	244.0	176.1	287.8	335.3	256.6	278.3	353.2	314.8	289.6	272.6	300.6	369.3	265.7	294.2	393.0	342.4	309.1	286.6	323.6	34.1	9.0	15.9	39.8	27.6	19.5	14.1	23.0

Total	B1H1	B1H2	B1H3	B1H4	B1H5	B1H6	B1H7	B1H8
EC kw	8433.1	2421.0	3301.0	6405.3	5173.1	4283.2	3023.1	6027.3
CD (\$)	1686.6	484.2	660.2	1281.1	1034.6	856.6	604.6	1205.5
CDP (\$)	8044.1	6053.0	6344.4	7372.5	6964.4	6669.7	6252.4	7247.3
CMG (\$)	674.7	193.8	264.2	512.5	413.9	342.7	241.9	482.3
CS (\$)	7369.4	5859.2	6080.2	6860.0	6550.5	6327.0	6010.4	6765.1

Table 6: Numerical Analysis results for Residential B2 for June-September 2020

Time (H)	Jun-Sept 2020																															
	EC (KW) B2H1	EC (KW) B2H2	EC (KW) B2H3	EC (KW) B2H4	EC (KW) B2H5	EC (KW) B2H6	EC (KW) B2H7	EC (KW) B2H8	CS (\$) B2H1	CS (\$) B2H2	CS (\$) B2H3	CS (\$) B2H4	CS (\$) B2H5	CS (\$) B2H6	CS (\$) B2H7	CS (\$) B2H8	CD (\$) B2H1	CD (\$) B2H2	CD (\$) B2H3	CD (\$) B2H4	CD (\$) B2H5	CD (\$) B2H6	CD (\$) B2H7	CD (\$) B2H8	CMG (\$) B2H1	CMG (\$) B2H2	CMG (\$) B2H3	CMG (\$) B2H4	CMG (\$) B2H5	CMG (\$) B2H6	CMG (\$) B2H7	CMG (\$) B2H8
1	23.86	19.145	35.54	2.37	23.65	11.19	3.55	33.68	234.3	233.12	237.23	228.9	234.25	231.12	229.2	236.77	236.21	234.65	240.08	229.1	236.14	232.02	229.49	239.47	1.9122	1.535	2.8466	0.193	1.8954	0.8986	0.2874	2.6978
2	22.69	25.025	32.46	3.2	22.1	12	4.895	32.48	234.01	234.59	236.46	229.11	233.86	231.32	229.54	236.47	235.83	236.6	239.06	229.37	235.63	232.28	229.93	239.07	1.8186	2.0054	2.6002	0.2594	1.7714	0.9634	0.395	2.6018
3	21.59	25.385	29.3	3.9	19.47	11.33	4.82	30.95	233.73	234.68	235.67	229.29	233.2	231.15	229.52	236.08	235.46	236.72	238.01	229.6	234.76	232.06	229.91	238.56	1.7306	2.0342	2.3474	0.3154	1.561	0.9098	0.389	2.4794
4	24.92	20.4	23.5	3.625	15.25	17.515	4.76	13.06	234.57	233.43	234.21	229.22	232.14	232.71	229.5	231.59	236.56	235.07	236.09	229.51	233.36	234.11	229.89	232.64	1.997	1.6354	1.8834	0.2934	1.2234	1.4046	0.3842	1.0482
5	25.1	20.67	18.96	3.787	31.15	23.77	4.21	15.57	234.61	233.5	233.07	229.26	236.13	234.28	229.36	232.22	236.62	235.16	234.59	229.56	238.63	236.18	229.7	233.47	2.0114	1.657	1.5202	0.3064	2.4954	1.905	0.3402	1.249
6	26.95	34.235	17.8	6.06	47.55	31.15	8.29	22.92	235.08	236.91	232.78	229.83	240.25	236.13	230.39	234.06	237.24	239.65	234.21	230.32	244.06	238.63	231.06	235.9	2.1594	2.7422	1.4274	0.4882	3.8074	2.4954	0.6666	1.837
7	26.77	36.375	23.12	5.8	47.75	35.9	14.98	36.86	235.03	237.44	234.11	229.76	240.3	237.32	232.07	237.57	237.18	240.36	235.97	230.23	244.12	240.2	233.27	240.52	2.145	2.9134	1.853	0.4674	3.8234	2.8754	1.2018	2.9522
8	27.69	48.205	26.36	7.9	42.3	39.75	18.5	34.68	235.26	240.42	234.93	230.29	238.93	238.29	232.95	237.02	237.48	244.28	237.04	230.93	242.32	241.48	234.44	239.8	2.2186	3.8598	2.1122	0.6354	3.3874	3.1834	1.4834	2.7778
9	26.55	46.79	27.5	7.3	38.2	45.05	21.4	46.22	234.98	240.06	235.21	230.14	237.9	239.62	233.68	239.92	237.1	243.81	237.42	230.73	240.96	243.23	235.4	243.62	2.1274	3.7466	2.2034	0.5874	3.0594	3.6074	1.7154	3.701
10	27.67	51.695	23.5	7	34.5	34.7	23.24	50.76	235.26	241.29	234.21	230.07	236.97	237.02	234.14	241.06	237.47	245.43	236.09	230.63	239.74	239.8	236.01	245.12	2.217	4.139	1.8834	0.5634	2.7634	2.7794	1.8626	4.0642
11	26.5	54.61	28.26	8.2	32.95	34.42	28.59	70.88	234.96	242.02	235.41	230.37	236.58	236.95	235.49	246.11	237.09	246.4	237.67	231.03	239.22	239.71	237.78	251.79	2.1234	4.3722	2.2642	0.6594	2.6394	2.757	2.2906	5.6738
12	30.09	50.85	28.8	9.5	43.36	30.02	28.16	69.87	235.87	241.08	235.54	230.69	239.2	235.85	235.38	245.86	238.28	245.15	237.85	231.46	242.67	238.25	237.64	251.45	2.4106	4.0714	2.3074	0.7634	3.4722	2.405	2.2562	5.593
13	29.64	46.9	31.7	9.2	42.9	29.7	22.785	70.19	235.75	240.09	236.27	230.62	239.08	235.77	234.03	245.94	238.13	243.84	238.81	231.36	242.52	238.15	235.86	251.56	2.3746	3.7554	2.5394	0.7394	3.4354	2.3794	1.8262	5.6186
14	29.04	50.86	33.5	9.496	42.8	30.5	24.05	69.35	235.6	241.08	236.72	230.69	239.06	235.97	234.35	245.73	237.93	245.15	239.41	231.46	242.49	238.41	236.28	251.28	2.3266	4.0722	2.6834	0.7631	3.4274	2.4434	1.9274	5.5514
15	28.19	53.665	37.2	11.266	54.2	32.47	21.51	71.59	235.39	241.79	237.65	231.14	241.92	236.46	233.71	246.29	237.65	246.08	240.63	232.04	246.26	239.06	235.43	252.02	2.2586	4.2966	2.9794	0.9047	4.3394	2.601	1.7242	5.7306
16	27.67	50.1	43.84	14.324	58.8	31.76	22.255	73.16	235.26	240.89	239.32	231.91	243.08	236.28	233.9	246.68	237.47	244.9	242.83	233.05	247.78	238.83	235.68	252.54	2.217	4.0114	3.5106	1.1493	4.7074	2.5442	1.7838	5.8562
17	30.19	47.898	40.6	13.182	67.4	36.29	19.23	75.63	235.89	240.34	238.51	231.62	245.24	237.42	233.14	247.3	238.31	244.17	241.76	232.68	250.63	240.33	234.68	253.36	2.4186	3.8353	3.2514	1.058	5.3954	2.9066	1.5418	6.0538
18	32.57	53	40.2	16.4	65.75	40.063	16.7	71.90	236.49	241.62	238.4	232.43	244.82	238.37	232.5	246.37	239.1	245.86	241.62	233.74	250.09	241.58	233.84	252.12	2.609	4.2434	3.2194	1.3154	5.2634	3.2085	1.3394	5.7554
19	28.14	54.328	46.2	15.09	74.7	50.25	13.14	72.24	235.38	241.95	239.91	232.1	247.07	240.93	231.61	246.45	237.63	246.3	243.61	233.31	253.05	244.95	232.66	252.24	2.2546	4.3497	3.6994	1.2106	5.9794	4.0234	1.0546	5.7826
20	32.08	55.75	49.64	13.7	78.15	56.765	15.12	69.40	236.37	242.31	240.78	231.75	247.94	242.57	232.11	245.74	238.94	246.77	244.75	232.85	254.19	247.11	233.32	251.3	2.5698	4.4634	3.9746	1.0994	6.2554	4.5446	1.213	5.5554
21	27.84	51.76	49.5	13.78	65.45	67.28	13.095	67.60	235.3	241.31	240.74	231.77	244.75	245.21	231.6	245.29	237.53	245.45	244.7	232.87	249.99	250.59	232.65	250.7	2.2306	4.1442	3.9634	1.1058	5.2394	5.3858	1.051	5.4114
22	28.89	51.13	43.64	11.95	39	50.35	10.375	55.00	235.56	241.15	239.27	231.31	238.1	240.95	230.91	242.12	237.88	245.24	242.76	232.27	241.23	244.99	231.75	246.53	2.3146	4.0938	3.4946	0.9594	3.1234	4.0314	0.8334	4.4034
23	26.34	41.13	45.9	9.6	34.65	17.85	10.5	52.01	234.92	238.64	239.84	230.72	237.01	232.79	230.94	241.37	237.03	241.93	243.51	231.49	239.79	234.22	231.79	245.54	2.1106	3.2938	3.6754	0.7714	2.7754	1.4314	0.8434	4.1642

Total	B2H1	B2H2	B2H3	B2H4	B2H5	B2H6	B2H7	B2H8
EC (KW)	631	990	777	207	1022	770	354	1206
CD (\$)	126	198	155	41	204	154	71	241
CDP (\$)	5460	5579	5508	5320	5590	5506	5368	5651
CMG (\$)	51	79	62	17	82	62	28	97
CS (\$)	5410	5500	5446	5303	5508	5444	5340	5554

Table 7: Numerical Analysis results for Residential B1 for October 2020 – February 2021

Time (H)	Oct 2020- Feb 2021																															
	EC kw B1H1	EC kw B1H2	EC kw B1H3	EC kw B1H4	EC kw B1H5	EC kw B1H6	EC kw B1H7	EC kw B1H8	CS (\$) B1H1	CS (\$) B1H2	CS (\$) B1H3	CS (\$) B1H4	CS (\$) B1H5	CS (\$) B1H6	CS (\$) B1H7	CS (\$) B1H8	CDP (\$) B1H1	CDP (\$) B1H2	CDP (\$) B1H3	CDP (\$) B1H4	CDP (\$) B1H5	CDP (\$) B1H6	CDP (\$) B1H7	CDP (\$) B1H8	CMG (\$) B1H1	CMG (\$) B1H2	CMG (\$) B1H3	CMG (\$) B1H4	CMG (\$) B1H5	CMG (\$) B1H6	CMG (\$) B1H7	CMG (\$) B1H8
1	373.1	128.0	163.6	253.0	367.5	205.5	155.0	225.0	258.1	227.8	232.2	243.2	257.4	237.4	231.1	239.8	287.9	238.0	245.3	263.5	286.8	253.8	243.5	257.8	29.9	10.2	13.1	20.2	29.4	16.4	12.4	18.0
2	348.3	140.0	147.1	135.7	159.9	188.0	125.6	178.0	255.0	229.3	230.2	228.8	231.7	235.2	227.5	234.0	282.9	240.5	241.9	239.6	244.5	250.3	237.6	248.2	27.9	11.2	11.8	10.9	12.8	15.0	10.0	14.2
3	323.0	126.7	124.4	100.0	200.3	150.9	114.3	164.4	251.9	227.7	227.4	224.3	236.7	230.6	226.1	232.3	277.7	237.8	237.3	232.3	252.8	242.7	235.3	245.4	25.8	10.1	10.0	8.0	16.0	12.1	9.1	13.1
4	341.0	132.7	124.4	87.7	106.5	151.2	107.0	162.0	254.1	228.4	227.4	222.8	225.1	230.7	225.2	232.0	281.4	239.0	237.3	229.8	233.7	242.8	233.8	245.0	27.3	10.6	10.0	7.0	8.5	12.1	8.6	13.0
5	343.0	124.0	120.6	96.8	133.7	107.5	97.1	184.0	254.4	227.3	226.9	224.0	228.5	225.3	224.0	234.7	281.8	237.2	236.5	231.7	239.2	233.9	231.8	249.5	27.4	9.9	9.6	7.7	10.7	8.6	7.8	14.7
6	346.2	133.8	163.5	157.9	180.0	102.7	98.1	230.4	254.8	228.5	232.2	231.5	234.2	224.7	224.1	240.5	282.5	239.2	245.3	244.1	248.6	232.9	232.0	258.9	27.7	10.7	13.1	12.6	14.4	8.2	7.8	18.4
7	326.5	137.8	183.0	209.7	200.7	101.8	138.3	325.3	252.3	229.0	234.6	237.9	236.8	224.6	229.1	252.2	278.4	240.0	249.2	254.7	252.8	232.7	240.1	278.2	26.1	11.0	14.6	16.8	16.1	8.1	11.1	26.0
8	336.2	127.5	176.0	273.6	213.9	109.0	140.1	348.7	253.5	227.7	233.7	245.8	238.4	225.5	229.3	255.1	280.4	237.9	247.8	267.7	255.5	234.2	240.5	283.0	26.9	10.2	14.1	21.9	17.1	8.7	11.2	27.9
9	372.4	123.1	190.0	313.4	297.2	127.2	149.2	394.4	258.0	227.2	235.5	250.7	248.7	227.7	230.4	260.7	287.8	237.1	250.7	275.8	272.5	237.9	242.4	292.3	29.8	9.8	15.2	25.1	23.8	10.2	11.9	31.6
10	507.2	139.1	212.7	265.7	226.0	155.1	141.8	399.9	274.6	229.2	238.3	244.8	239.9	231.2	229.5	261.4	315.2	240.3	255.3	266.1	258.0	243.6	240.9	293.4	40.6	11.1	17.0	21.3	18.1	12.4	11.3	32.0
11	542.1	153.1	242.9	257.7	260.0	167.3	155.4	466.9	278.9	230.9	242.0	243.8	244.1	232.7	231.2	269.7	322.3	243.2	261.4	264.4	264.9	246.0	243.6	307.0	43.4	12.2	19.4	20.6	20.8	13.4	12.4	37.3
12	563.8	151.0	238.4	228.4	262.1	173.6	158.4	507.7	281.6	230.6	241.4	240.2	244.4	233.4	231.6	274.7	326.7	242.7	260.5	258.5	265.3	247.3	244.2	315.3	45.1	12.1	19.1	18.3	21.0	13.9	12.7	40.6
13	544.4	148.3	250.3	207.1	296.1	167.3	154.2	537.9	279.2	230.3	242.9	237.6	248.6	232.7	231.0	278.4	322.8	242.2	262.9	254.1	272.3	246.1	243.4	321.5	43.6	11.9	20.0	16.6	23.7	13.4	12.3	43.0
14	474.9	151.8	268.3	216.9	322.0	145.2	121.9	488.4	270.6	230.8	245.1	238.8	251.8	229.9	227.1	272.3	308.6	242.9	266.6	256.1	277.5	241.6	236.8	311.4	38.0	12.1	21.5	17.3	25.8	11.6	9.8	39.1
15	549.6	158.4	272.2	419.7	507.1	207.1	155.0	588.0	279.9	231.6	245.6	263.8	274.6	237.6	231.1	284.6	323.8	244.2	267.4	297.4	315.2	254.1	243.5	331.7	44.0	12.7	21.8	33.6	40.6	16.6	12.4	47.0
16	560.2	171.6	290.5	480.3	578.1	283.9	191.2	613.6	281.2	233.2	247.9	271.3	283.4	247.1	235.6	287.8	326.0	246.9	271.1	309.7	329.6	269.8	250.9	336.9	44.8	13.7	23.2	38.4	46.2	22.7	15.3	49.1
17	571.0	176.0	310.2	472.6	664.8	273.7	217.0	601.5	282.5	233.7	250.3	270.4	294.1	245.8	238.8	286.3	328.2	247.8	275.1	308.2	347.3	267.7	256.2	334.4	45.7	14.1	24.8	37.8	53.2	21.9	17.4	48.1
18	547.4	184.0	301.6	443.5	572.5	264.8	220.7	657.4	279.6	234.7	249.2	266.8	282.7	244.7	239.3	293.2	323.4	249.4	273.4	302.2	328.5	265.9	256.9	345.8	43.8	14.7	24.1	35.5	45.8	21.2	17.7	52.6
19	579.3	179.2	310.7	520.0	658.8	263.3	230.7	713.5	283.5	234.1	250.4	276.2	293.4	244.5	240.5	300.1	329.9	248.5	275.2	317.8	346.1	265.6	259.0	357.2	46.3	14.3	24.9	41.6	52.7	21.1	18.5	57.1
20	554.2	171.4	320.5	560.0	701.2	289.9	229.6	639.5	280.4	233.2	251.6	281.2	298.6	247.8	240.4	291.0	324.8	246.9	277.2	326.0	354.7	271.0	258.7	342.1	44.3	13.7	25.6	44.8	56.1	23.2	18.4	51.2
21	522.3	178.0	339.0	585.6	676.4	282.1	239.6	609.5	276.5	234.0	253.9	284.3	295.5	246.8	241.6	287.3	318.3	248.2	281.0	331.2	349.6	269.4	260.8	336.0	41.8	14.2	27.1	46.9	54.1	22.6	19.2	48.8
22	544.1	177.9	318.8	536.9	582.1	241.6	222.5	606.2	279.2	234.0	251.4	278.3	283.9	241.8	239.5	286.9	322.7	248.2	276.9	321.3	330.4	261.2	257.3	335.4	43.5	14.2	25.5	43.0	46.6	19.3	17.8	48.5
23	541.0	162.4	324.4	576.8	582.2	251.3	220.2	480.0	278.8	232.1	252.1	283.2	283.9	243.0	239.2	271.3	322.1	245.1	278.0	329.4	330.5	263.1	256.8	309.7	43.3	13.0	25.9	46.1	46.6	20.1	17.6	38.4

Total	B1H1	B1H2	B1H3	B1H4	B1H5	B1H6	B1H7	B1H8
EC kw	10711	3476	5393	7399	8749	4410	3783	10122
CD (\$)	2142.2	695.2	1078.6	1479.8	1749.8	882.0	756.6	2024.4
CDP (\$)	7055.7	5583.4	5973.5	6381.7	6656.4	5773.4	5645.8	6935.8
CMG (\$)	856.9	278.1	431.4	591.9	699.9	352.8	302.6	809.8
CS (\$)	6198.8	5305.3	5542.0	5789.8	5956.5	5420.6	5343.2	6126.1

Table 8: Numerical Analysis results for Residential B2 for October 2020 – February 2021

Time (H)	Oct 2020- Feb 2021																															
	EC (KW) B2H1	EC (KW) B2H2	EC (KW) B2H3	EC (KW) B2H4	EC (KW) B2H5	EC (KW) B2H6	EC (KW) B2H7	EC (KW) B2H8	CS (\$) B2H1	CS (\$) B2H2	CS (\$) B2H3	CS (\$) B2H4	CS (\$) B2H5	CS (\$) B2H6	CS (\$) B2H7	CS (\$) B2H8	CD (\$) B2H1	CD (\$) B2H2	CD (\$) B2H3	CD (\$) B2H4	CD (\$) B2H5	CD (\$) B2H6	CD (\$) B2H7	CD (\$) B2H8	CMG (\$) B2H1	CMG (\$) B2H2	CMG (\$) B2H3	CMG (\$) B2H4	CMG (\$) B2H5	CMG (\$) B2H6	CMG (\$) B2H7	CMG (\$) B2H8
1.00	121.92	48.82	93.83	11.92	72.84	41.96	19.10	97.34	227.06	218.03	223.59	213.47	221.00	217.18	214.36	224.02	236.81	221.93	231.09	214.43	226.82	220.54	215.89	231.81	9.75	3.91	7.51	0.95	5.83	3.36	1.53	7.79
2.00	115.95	63.81	85.69	16.10	68.07	45.00	25.00	93.87	226.32	219.88	222.58	213.99	220.41	217.56	215.09	223.59	235.59	224.99	229.44	215.28	225.85	221.16	217.09	231.10	9.28	5.11	6.86	1.29	5.45	3.60	2.00	7.51
3.00	110.32	64.73	77.35	19.62	59.97	42.49	25.93	89.45	225.63	219.99	221.55	214.42	219.41	217.25	215.20	223.05	234.45	225.17	227.74	215.99	224.20	220.65	217.28	230.20	8.83	5.18	6.19	1.57	4.80	3.40	2.07	7.16
4.00	127.34	52.02	62.04	18.23	46.97	65.68	25.61	37.74	227.73	218.42	219.66	214.25	217.80	220.11	215.16	216.66	237.91	222.59	224.63	215.71	221.56	225.37	217.21	219.68	10.19	4.16	4.96	1.46	3.76	5.25	2.05	3.02
5.00	128.40	52.71	50.05	19.05	95.94	89.14	22.65	45.00	227.86	218.51	218.18	214.35	223.85	223.01	214.80	217.56	238.13	222.73	222.19	215.88	231.52	230.14	216.61	221.16	10.27	4.22	4.00	1.52	7.68	7.13	1.81	3.60
6.00	137.71	87.30	46.99	30.48	146.45	116.81	44.60	66.24	229.01	222.78	217.80	215.76	230.09	226.43	217.51	220.18	240.02	229.77	221.56	218.20	241.80	235.77	221.08	225.48	11.02	6.98	3.76	2.44	11.72	9.35	3.57	5.30
7.00	136.79	92.76	61.04	29.17	147.00	134.63	80.59	106.53	228.89	223.46	219.54	215.60	230.15	228.63	221.95	225.16	239.84	230.88	224.42	217.94	241.91	239.40	228.40	233.68	10.94	7.42	4.88	2.33	11.76	10.77	6.45	8.52
8.00	141.50	122.92	69.59	39.74	130.28	149.06	99.53	100.23	229.47	227.18	220.59	216.91	228.09	230.41	224.29	224.38	240.79	237.01	226.16	220.09	238.51	242.33	232.25	232.40	11.32	9.83	5.57	3.18	10.42	11.93	7.96	8.02
9.00	135.67	119.31	72.60	36.72	117.66	168.94	115.13	133.58	228.76	226.74	220.97	216.53	226.53	232.86	226.22	228.50	239.61	236.28	226.77	219.47	235.94	246.38	235.43	239.18	10.85	9.55	5.81	2.94	9.41	13.52	9.21	10.69
10.00	141.39	131.82	62.04	35.21	106.26	130.13	125.03	146.70	229.46	228.28	219.66	216.35	225.12	228.07	227.44	230.12	240.77	238.83	224.63	219.17	233.62	238.48	237.44	241.85	11.31	10.55	4.96	2.82	8.50	10.41	10.00	11.74
11.00	135.42	139.26	74.61	41.00	101.41	129.08	153.81	204.84	228.72	229.20	221.21	217.06	224.52	227.94	231.00	237.30	239.56	240.34	227.18	220.34	232.64	238.27	243.30	253.69	10.83	11.14	5.97	3.28	8.11	10.33	12.31	16.39
12.00	153.76	129.67	76.03	47.68	133.55	114.00	151.50	201.92	230.99	228.01	221.39	217.89	228.49	226.08	230.71	236.94	243.29	238.39	227.47	221.70	239.18	235.20	242.83	253.09	12.30	10.37	6.08	3.81	10.68	9.12	12.12	16.15
13.00	151.46	119.60	83.00	46.28	132.13	111.38	122.58	202.85	230.71	226.77	222.25	217.72	228.32	225.75	227.14	237.05	242.82	236.34	228.89	221.42	238.89	234.66	236.95	253.28	12.12	9.57	6.64	3.70	10.57	8.91	9.81	16.23
14.00	149.00	129.69	88.43	47.76	131.82	114.38	129.39	200.42	230.40	228.02	222.92	217.90	228.28	226.13	227.98	236.75	242.32	238.39	230.00	221.72	238.83	235.28	238.33	252.79	11.92	10.38	7.07	3.82	10.55	9.15	10.35	16.03
15.00	144.05	133.00	98.25	56.67	166.94	121.76	115.70	206.90	229.79	228.43	224.13	219.00	232.62	227.04	226.29	237.55	241.31	239.07	231.99	223.53	245.97	236.78	235.54	254.10	11.52	10.64	7.86	4.53	13.35	9.74	9.26	16.55
16.00	141.39	127.76	115.74	72.05	181.10	119.10	119.73	207.00	229.46	227.78	226.29	220.90	234.37	226.71	226.79	237.56	240.77	238.00	235.55	226.66	248.85	236.24	236.37	254.12	11.31	10.22	9.26	5.76	14.49	9.53	9.58	16.56
17.00	154.27	122.14	107.18	66.31	207.59	136.09	103.46	218.57	231.05	227.08	225.24	220.19	237.64	228.81	224.78	238.99	243.39	236.86	233.81	225.49	254.24	239.69	233.05	256.48	12.34	9.77	8.57	5.30	16.61	10.89	8.28	17.49
18.00	166.43	135.15	106.13	82.49	202.51	150.24	89.85	207.79	232.55	228.69	225.11	222.19	237.01	230.55	223.10	237.66	245.87	239.50	233.60	228.79	253.21	242.57	230.28	254.29	13.31	10.81	8.49	6.60	16.20	12.02	7.19	16.62
19.00	143.80	138.54	121.97	75.90	230.08	188.44	70.69	208.77	229.76	229.11	227.06	221.37	240.41	235.27	220.73	237.78	241.26	240.19	236.82	227.45	258.82	250.35	226.39	254.49	11.50	11.08	9.76	6.07	18.41	15.08	5.66	16.70
20.00	163.93	142.16	131.05	68.91	240.70	212.87	81.35	200.57	232.25	229.56	228.18	220.51	241.73	238.29	222.05	236.77	245.36	240.93	238.67	226.02	260.98	255.32	228.55	252.82	13.11	11.37	10.48	5.51	19.26	17.03	6.51	16.05
21.00	142.26	132.60	133.00	69.31	203.00	252.10	70.45	195.36	229.57	228.38	228.43	220.56	237.07	243.13	220.70	236.13	240.95	238.98	239.07	226.11	253.31	263.30	226.34	251.76	11.38	10.61	10.64	5.55	16.24	20.17	5.64	15.63
22.00	147.63	130.35	115.21	60.11	120.00	188.81	55.82	158.95	230.23	228.10	226.23	219.42	226.82	235.32	218.89	231.63	242.04	238.53	235.45	224.23	236.42	250.42	223.36	244.35	11.81	10.43	9.22	4.81	9.60	15.11	4.47	12.72
23.00	134.60	104.88	121.18	48.29	106.72	66.94	56.49	150.40	228.62	224.95	226.97	217.96	225.18	220.27	218.98	230.57	239.39	233.34	236.66	221.83	233.72	225.62	223.50	242.61	10.77	8.39	9.69	3.86	8.54	5.36	4.52	12.03

Total	B2H1	B2H2	B2H3	B2H4	B2H5	B2H6	B2H7	B2H8
EC (KW)	3225	2521	2053	1039	3149	2889	1904	3481
CD (\$)	645	504	411	208	630	578	381	696
CDP (\$)	5532	5389	5294	5087	5517	5464	5263	5584
CMG (\$)	258	202	164	83	252	231	152	278
CS (\$)	5274	5187	5130	5004	5265	5233	5111	5306

4.9.3 Obtained Numerical Results:

Using Matlab software and basing on an arbitrary data (see Matlab code in Annex) we plot the curves of decision according hours, energy generated in impute.

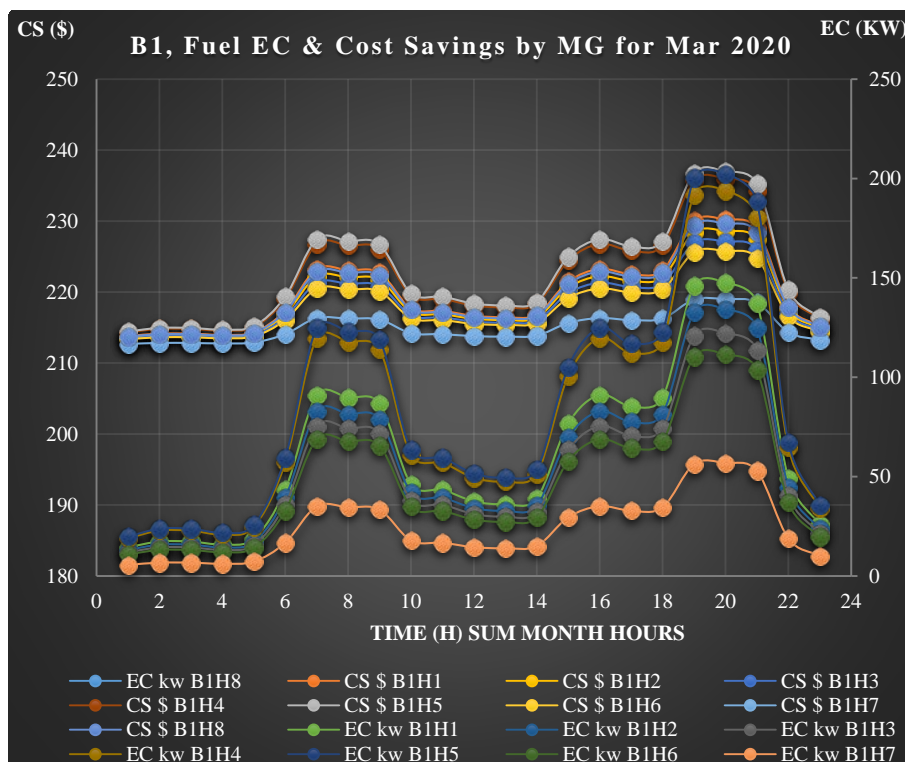
In Figure 47 a, b and 48 a, b are respectively the plots of the results obtained by numerical analysis for the Cost saving (CS) of the energy consumption (EC) for all households of Block-Flats 1 (B1) and Block-Flats 2 (B2) over the two periods of time, before Lockdown March 2020 and during Lockdown April-May 2020.

Analysis for the Energy Consumption (EC) were done per Period-Hour (number of Hours per interval of time) for the hours of the day, which allow us to better understand the Saving that can be done per hour and during the studied interval of time.

A Period-Hour can be illustrated as following:

For March 2020 = Period-Hour between 10:00 AM and 11:00 AM = 1H * 30 Days = 30 hours

For April-May 2020 = Period-Hour between 10:00 -11:00 AM = 1H * (30 +31) Days = 61 hours.



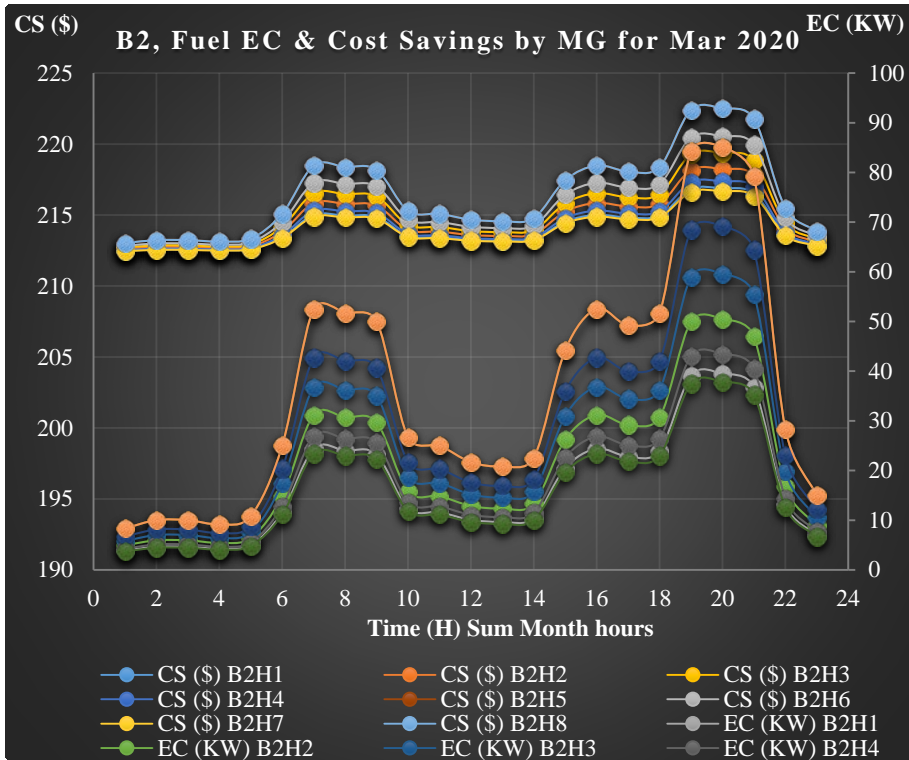
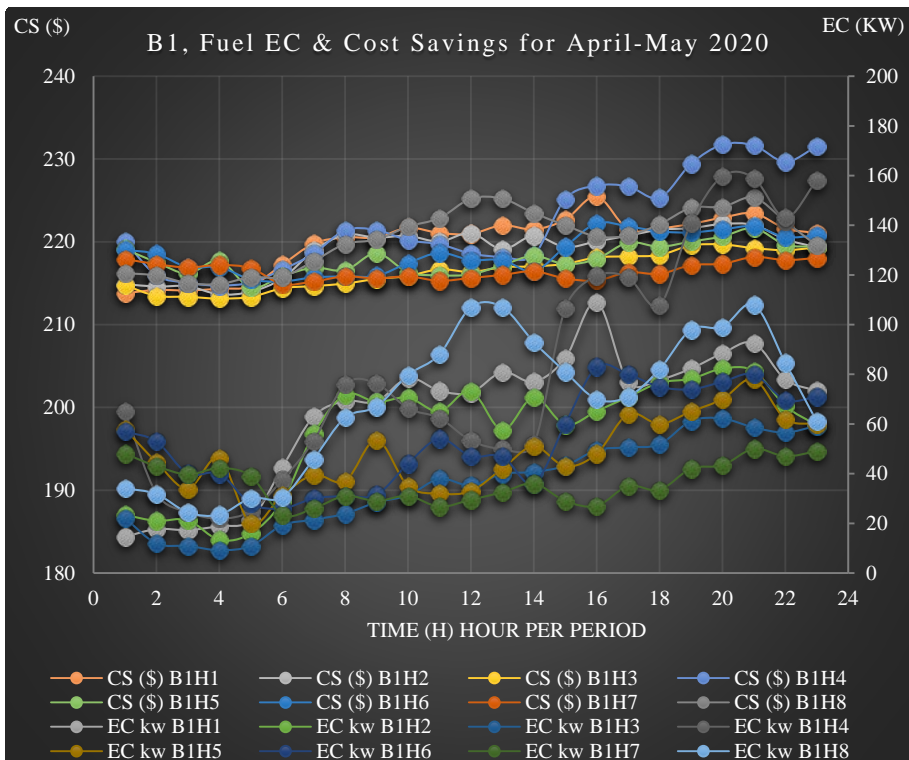


Figure 47: a, b obtained by numerical analysis for the Cost saving (CS) of the energy consumption for March 2020 (Before Lockdown) (EC) for households of B1 and B2.



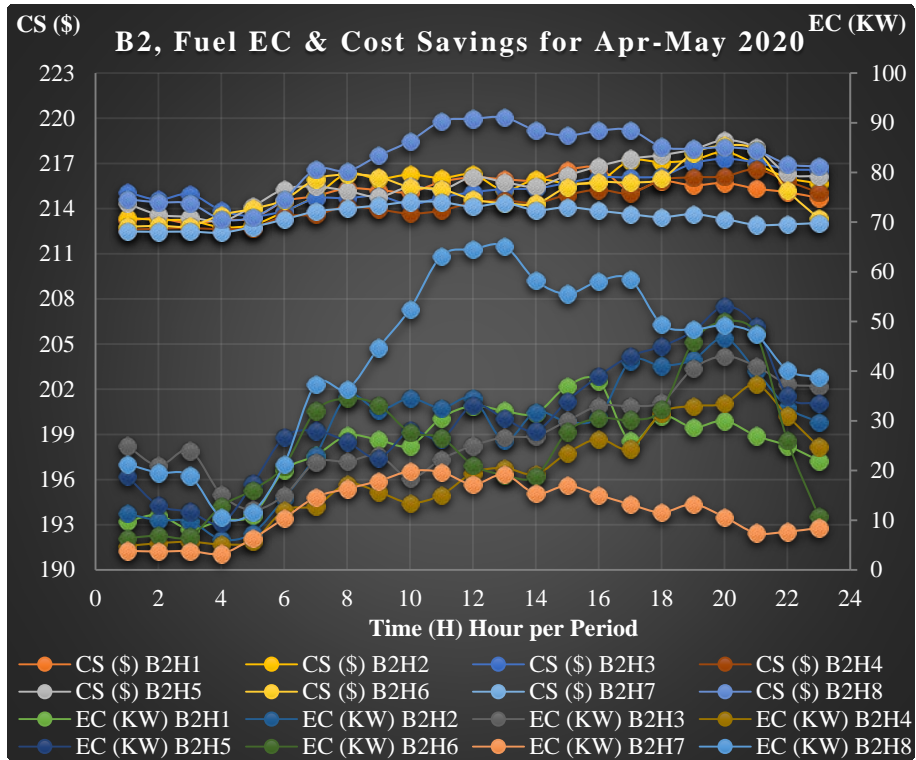


Figure 48: a, b obtained by numerical analysis for the Cost saving (CS) of the energy consumption for Apr-May 2020 (during Lockdown) for B1 and B2.

Besides a possible financial gain that can be achieved by integrating a micro grid for power generation instead of the Diesel Generators, this cost reduction is valid for all conditions of energy consumptions (times and season). It has been observed from our model that health-care cost play a major role in the total bill reduction due to the consistent quantity of emitted air pollution.

Financial Study for the real paid bills of the Energy consumption (EC) shows a high compatibility with the obtained Cost Savings values, e.g if we take the case of B1H1 that has consumed 1446 KW over a period of March 2020 we can identify the following:

- Average price per KW of Electricity by fuel oil = $(7.7 \text{ ¢ EDL} + 33 \text{ ¢ DG})/2 = 20.35 \text{ cents}$.
- B1H1 total real paid bill = $1446\text{KW} * 0.235\$ = 340 \text{ USD}$.
- B1H1 average real fees saving = $340 - 115.7 = 224.3 \text{ USD}$, results obtained by the Model and equivalent to 66 % of the total real bill, by implementing the proposed Micro-grid for assistance in the Energy generation.

For April and May 2020, we conclude obviously the same benefit from the fact of integrating an alternative source of Energy generation.

For more accurateness in the study and better understanding of the energy consumption variation during the whole seasons, the data measurements and analysis have been also considered for summer season where energy consumption have recorded from June 01 to September 30, 2020 and cost savings were determined with the same numerical method.

In figures 49 a, b we provide the Energy consumption and cost saving for the residences of B1 and B2 where an average saving of 307\$ and 205\$ respectively per Hour-Period can be achieved.

Each Period-Hour of June-September 2020 = 1H * (30 + 31 + 31 +30) Days = 122 hours.

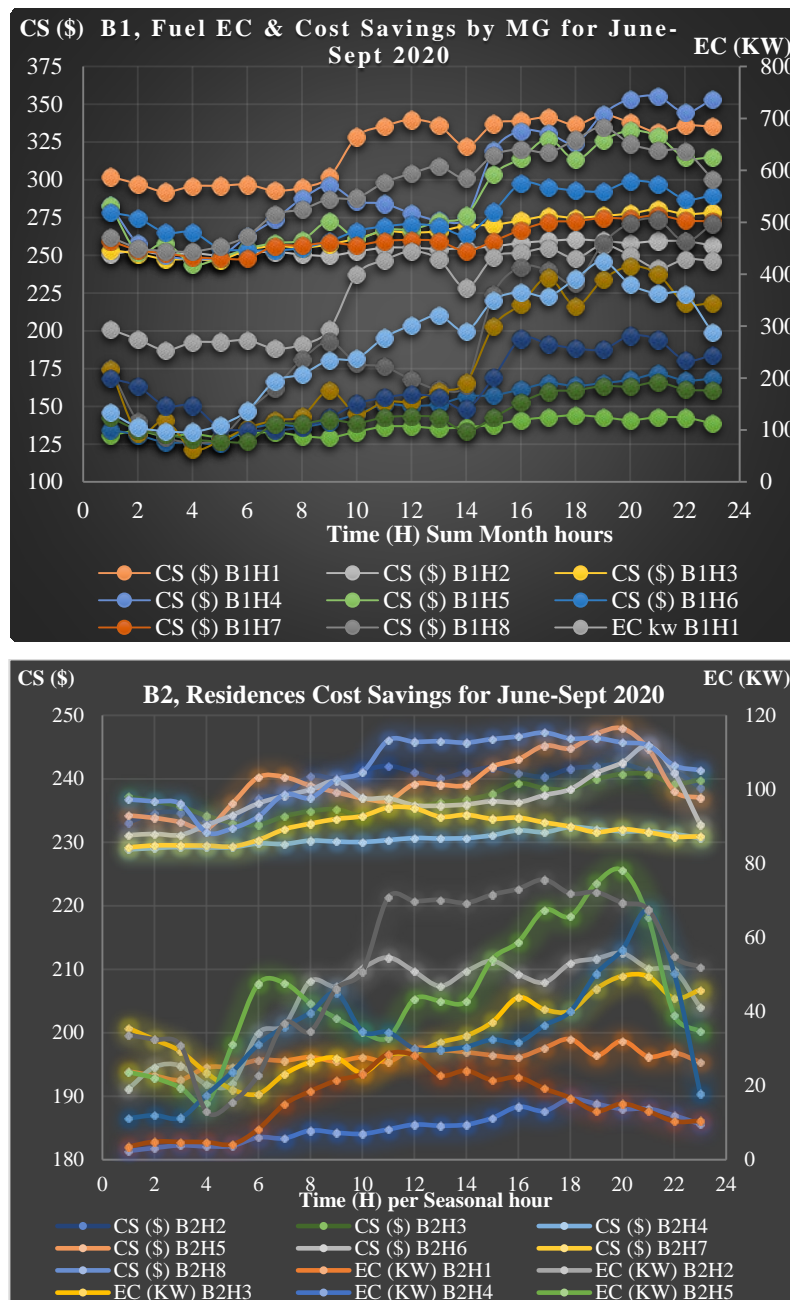


Figure 49 a, b: Energy Consumption and Cost saving for June-Sept, 2020 for B1 and B2.

In the aim of covering the cycle of a whole year, measurements for Energy consumption and data Analysis were realized for the period over Oct 2020 to Feb 2021. Figures 50 a, b provide the cost saving of the consumed energy for this period for the residences of B1 and B2.

One Period-Hour of Oct 2020-Feb 2021 = 1H * (31 + 30 + 30 + 31 + 28) Days = 151 hours.

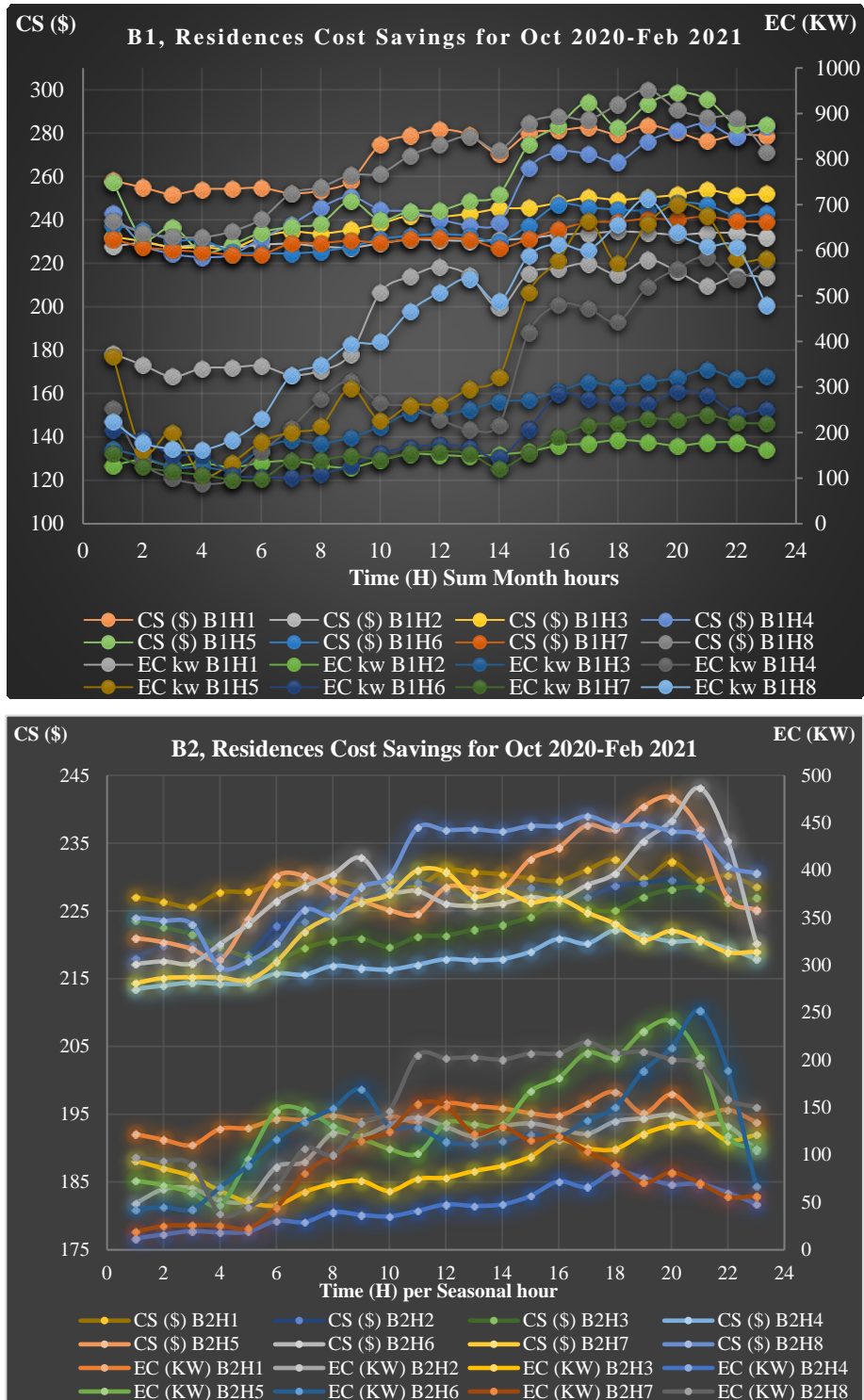


Figure 50 a, b: Energy Consumption and Cost saving for Oct 2020 to Feb 2021 for B1 and B2.

Figure 51 is a typical example for the details of data analysis, for B1H1 and B2 H1, that considered a comparison in the cost prices for same amount of consumed energy produced by Microgrid or by Fuel Diesel with Pollution Consequence and the possible cost saving.

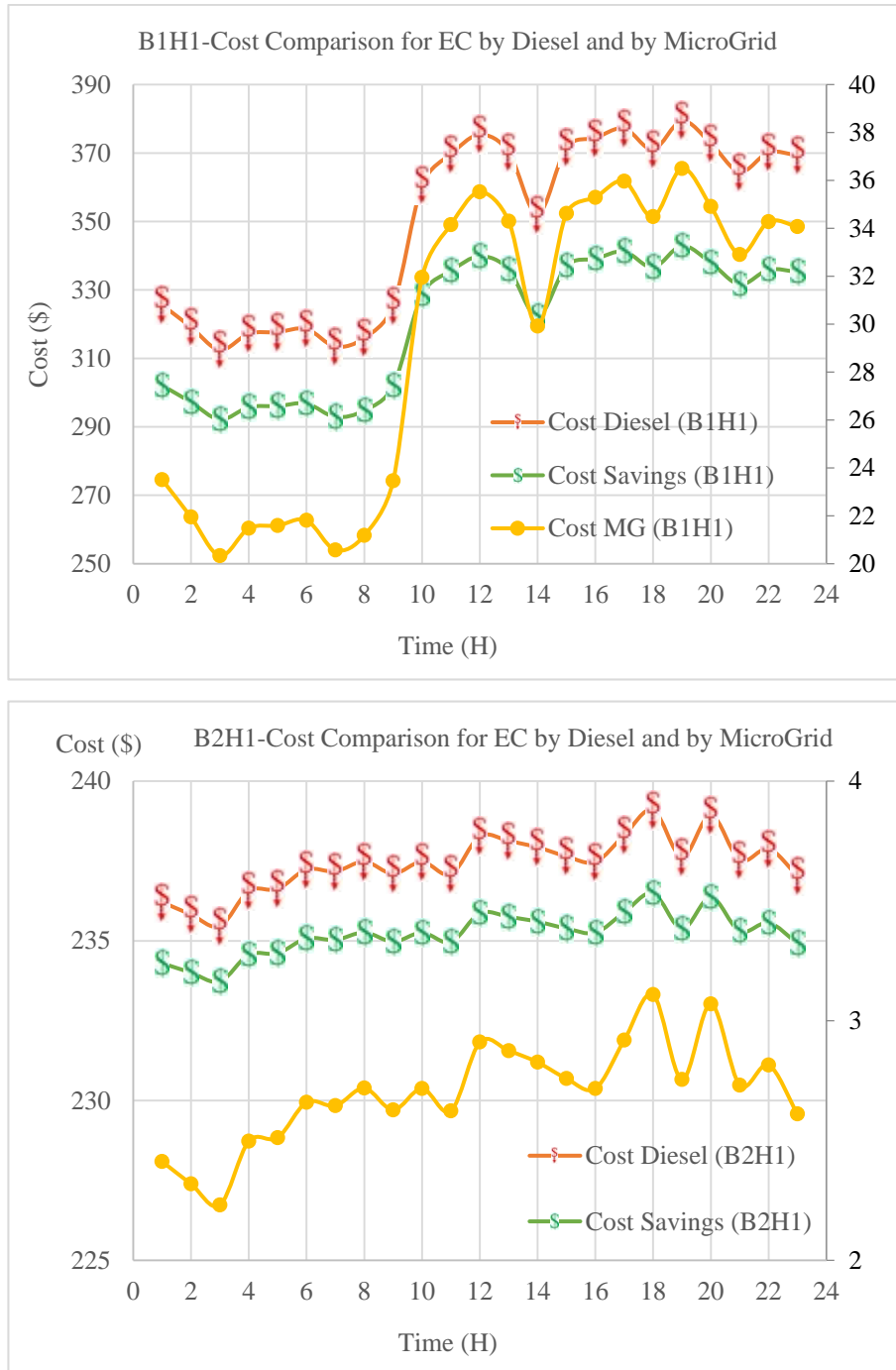


Figure 51: Data analysis details for cost prices and Cost Saving for an amount of EC produced by MG or Fuel Diesel with Pollution Consequence costs (B1H1 and B2H2).

Cost analysis for consumed energy over 1 year were done for both Block-Flats B1 and B2, figures 52, by determining the total real paid cost of the consumed energy by each household and then make a comparison for all data over the 4 seasons (cycle of one year).

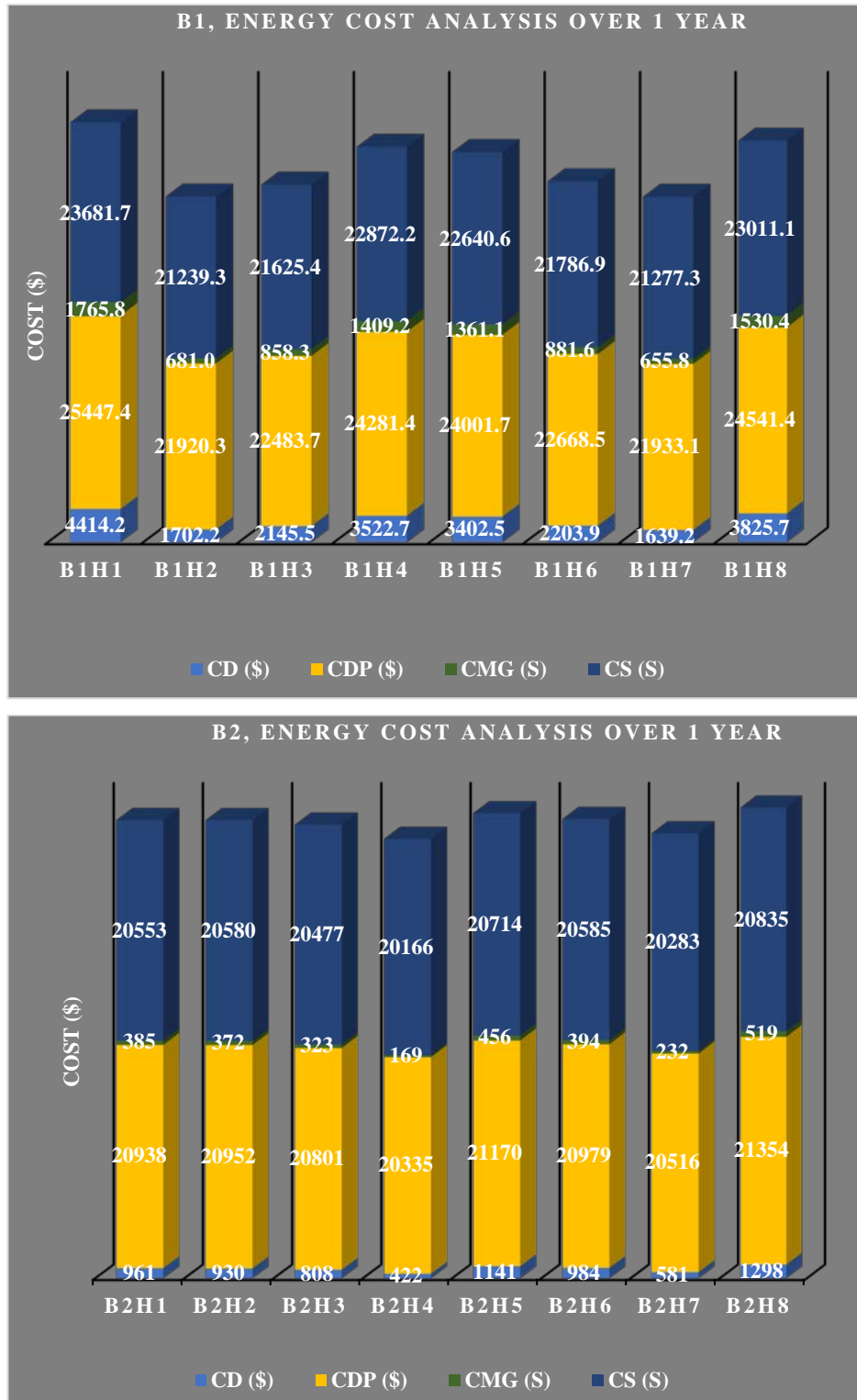


Figure 52: Cost analysis for one year of EC were for Block-Flats B1 and B2

Data analysis shows that by integrating to Micro-grid, direct real saving in the electricity bill is consistent in terms of yearly budget economy for the families, beside the long term benefits that can be harvested in terms of Health and environments issues.

For more details, we provide in table 9 the yearly direct real saving of each household in the B1 and B2 respectively:

$$\text{Direct real saving} = \text{Diesel Electricity Cost} - \text{Micro grid Electricity Cost} = \text{CD-CMG}$$

	B1H1	B1H2	B1H3	B1H4	B1H5	B1H6	B1H7	B1H8
EC (KW)	22071	8511	10727	17613	17012	11019	8196	19129
CD-CMG	2648	1021	1287	2114	2041	1322	983	2295
	B2H1	B2H2	B2H3	B2H4	B2H5	B2H6	B2H7	B2H8
EC (KW)	4806	4650	4041	2110	5704	4921	2905	6492
CD-CMG	577	558	485	253	684	590	349	779

Table 9: Possible direct real saving by switching to Micro grid electricity over 1 year for B1 and B2.

For all studied households the possible gain in the cost of energy production with micro grid system with respect to the fuel system is very clear and important in addition to the benefit that may be obtained for environment and public health.

Analysis for the **real paid bills** of the Energy consumption shows a high compatibility with the obtained Cost Saving (CS) values.

In order to justify the financial utility of integrating a Micro grid in the households, a detailed accounting verification for the real paid costs and hidden fees (environment and Health bill) was realized.

Table 10 present a two comparative cases of households that have been selected from B1 and B2 according to the Highest and Lowest Energy Consumption (EC) in each block in KW and over a period of June 01 to Sept 30, 2020:

June 01 to Sept 30, 2020	EC (KW)*	1 KW real prices	CD (\$)*	CDP (\$)*	CMG (\$)*	CS (\$)*
B1H1 (High)	8433 KW	0.077\$ EDL 0.33\$ DG	$8433 * (0.077 + 0.33) / 2$ = 1686 \$	8044\$	674.7\$	7369.4\$
B1H2 (Low)	2421 KW	0.077\$ EDL 0.33\$ DG	$2421 * (0.077 + 0.33) / 2$ = 484 \$	6053\$	193.8\$	5859\$
B2H4	207 KW	0.077\$ EDL 0.33\$ DG	$207 * (0.077 + 0.33) / 2$ = 41 \$	5320\$	17\$	5303\$
B2H8	1206 KW	0.077\$ EDL 0.33\$ DG	$241 * (0.077 + 0.33) / 2$ = 241\$	5651\$	97\$	5554\$
* EC = Energy Consumption in KW CD (\$) = Real cost of EC by Diesel production (\$) Calculated by Numerical Analysis: CDP (\$) = Cost of EC by Diesel production (\$) + Diesel Pollution consequence (\$). CMG (\$) = Cost of EC by Microgrid production (\$) CS (\$) = Expected Cost Saving						

Table 10: Comparison between the costs of EC by fuel and by Micro grid with respect to the values obtained by Simulation (B1H1 and B1H2).

From values given in the above table for the two households (B1H1 and B1H2) we notice an average saving of around 7000\$ in a period of 4 months, this amount actually encloses the paid fees for the pollution consequences hidden in the public health diseases treatment and the environment destruction.

Finally we have considered each Block-flats as a central unit of consumption, figure 53, that will allow to have a betel look at the level of possible saving that can be achieved by introducing the clean energies sources in our daily life. Good to mention that the big amount of the bill is paid for the consequence of the diesel uses, as the health bill paid for the treatments of affected people and the pollution residues that may have long terms effect on the environment.

Absolutely numbers were given to simulate the worst case scenario that may occurs from the diesel effect, where the total cost for diesel electricity production for B1 as 187277\$ enclose the regular cost of 114279 KW of consumed energy 22856\$, in addition to the health bill to treat 32 persons from chronic diseases (in average 4 persons per residence in B1) and the environment damage cost.

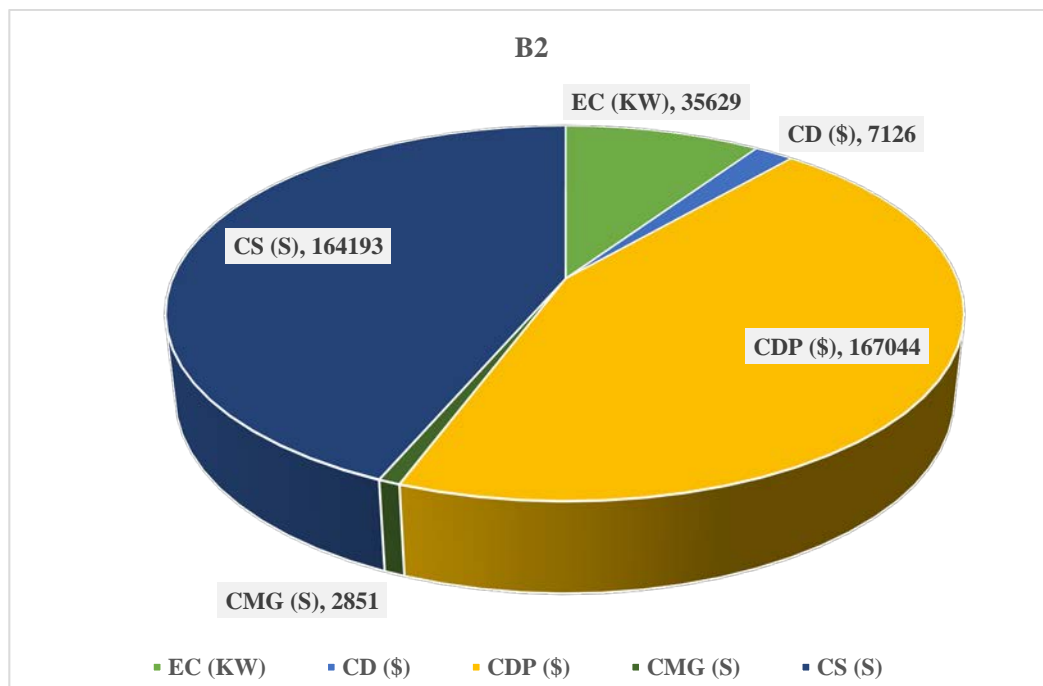
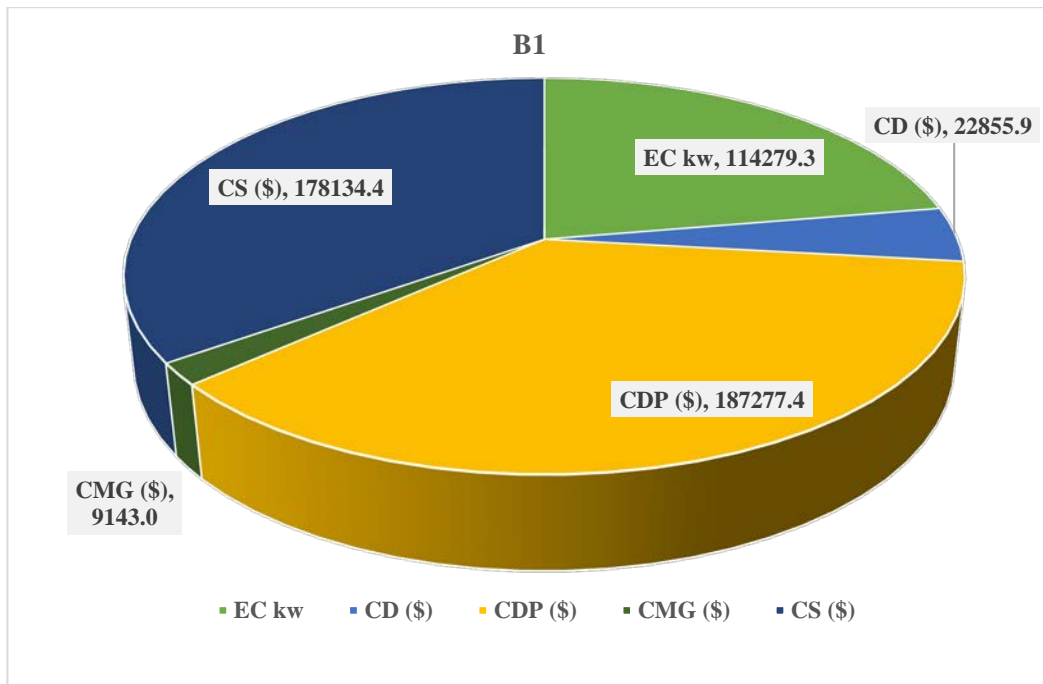


Figure 53: Total possible Cost saving obtained by numerical analysis where B1 and B2 are considered each as a central unit of consumption

4. 10 CONCLUSION

The electricity sector in Lebanon is considered as one of the main causes of air pollution after transportation. Problem in this due to the old networks easily hacked and the strong reliance on fuel in addition to many technical and non-technical losses such as illegal connections and meter manipulations. Electricity demand that has inflated the last 2 decays in Lebanon has led to an alternative sources of production, private Diesel Generators operating with fossil fuel, which allowed the citizens to fill the shortage of Electricity supply by EDL.

A case study was realized among Lebanese Households for electric consumption through real data collected by installing power-meter devices in complex of flats situated in different regions of Beirut. The study was conducted by numerical treatment for the collected data in order to explore the benefits that can be obtained from integrating Micro-grids management systems handling clean sources in parallel to the EDL Supply. A comparison was done between the Costs of the private diesel generators supply and the proposed Microgrids system, where results showed clearly the importance of integrating such devices in residential.

4. 11 Annex: Mat lab Code

```
> clear
Wi=expand (2.5,24,1); % quantity of energy for every hour obtained arbitrary by generating random law with
exponential mean 2.5
Wmax=max (Wi); % maximum energy by day
% cost according Diesel generator
LwiD= Wi./11.1;% quantity of liter of diesel needed in order to generate Wi, information from net 1 liter de
carburant diesel = 40 MJ = 11,1 kWh
UCD= 5000; % unit cost of generators used in order to satisfy the Wi needed (cost generator + installation)
ICD= UCD / (365*24); %unit cost of diesel generator
CUo2= 5; % unit cost of impact CO2 expressed by mu/TCO2
gd= 0.002640;% quantity of CO2 dissipate by one liter of diesel using Diesel generator
N= 15; % Mean Number of patient in hospital by year
disp= 1200; % mean dispense of one patient by year
Ecdwi= (CUo2.* gd.* LwiD)+ ((N.*disp)./(365*24)) ; % environment cost according to diesel generator for
every hour i according to wi
Cld= 1.5 ; %unit cost of diesel by liter
Ccdwi= Cld.*LwiD; % Cost of consumption for every hour according to wi
Mcd= 3000; % unit cost of corrective maintenance for Diesel generator
Mpd= 300; % unit cost of corrective maintenance for Diesel generator
Td= 31.62; % optimal preventive maintenance frequency considering as failure law weibull (shape =2, scale
=100) the result is obtained from other Matlab code of maintenance
MCD= 18.97; % Nominal total cost by hour according to Mc, Mp and failure law; the result is obtained from
other Matlab code of maintenance
MCDwi= (Wi./Wmax).*MCD; % total cost of maintenance for every i hour taking into account maintenance
data failure data and the real energy wi for every hour
TCDi= MCDwi+Ccdwi+Ecdwi+ICD; % Total cost with using Diesel generator for every hour i using Wi as
input data
% cost according MG
UCMG= 50000; % unit cost of generators used in order to satisfy the Wi needed (cost generator + installation)
ICMG= UCMG/ (365*24); %unit cost of MG choose arbitrary
CUo2= 5; % unit cost of impact CO2 expressed by mu/TCO2
gmg= 0.004;% quantity of CO2 dissipate by KW when using MG if it exists and fixed arbitrary if not take gd=0
NBR=3; % Number of battery recycled by year if it exists and according the type of MG used
RC= 10; % environmental impact of recycling of one battery expressed by mu
Ecmgwi = (CUo2.* gmg.* Wi ) + ((NBR.*RC)./(365.*24)); % environment cost according to MG for every
hour i according to wi
Clmg= 0.3; %unit cost KW using MG expressed by mu/KW fixed arbitrary
Ccmgwi= Clmg.*Wi; % Cost of consumption for every hour according to wi
Mcmg= 1000; % unit cost of corrective maintenance for MG fixed arbitrary
Mpmg= 100; % unit cost of corrective maintenance for MG fixed arbitrary
Tmg= 42.95 ; % optimal preventive maintenance frequency considering as failure law weibull (shape =1.3, scale
=100)the result is obtained from other Matlab code of maintenance
MCmg= 10.08; % Nominal total cost by hour according to Mc, Mp and failure law; the result is obtained from
other Matlab code of maintenance
MCmgwi= (Wi./Wmax).*MCmg; % total cost of maintenance for every i hour taking into account maintenance
data failure data and the real energy wi for every hour
TCmgi= MCmgwi+Ccmgwi+Ecmgwi+ICMG; % Total cost with using Diesel generator for every hour i using
Wi as input data
DEC=TCmgi-TCDi;
Hours =[1:1:24];
Y= zeros (1,24);
Plot (hours,decision,hours,Y)
Plot (hours,DEC,hours,Y,hours,Wi)
```

GENERAL CONCLUSION

During this work we have highlighted on the causes of air pollution produced by outdoor and indoor sources, where we have discussed the negative impact on public health and economy sector. Also it has been mentioned that developing countries are facing the highest rate of the damaging causes of these sources more than the developed countries since in the citizens are still relying on the traditional ways in most of their life's activities either inside their houses, as biomass energy production for living, or outside such as electricity generation obtained from classical burning fossil fuel. An Obvious conclusion is that in both cases the citizens will be charged the heaviest consequences either at health or economy levels.

Also we have shown that in Lebanon there are many sources of air pollution, where traffic, diesel generators and different types of wastes are a major sources of emission. An accurate and sustainable solutions, even a starting point towards cleaner Lebanese environment becomes a necessity and urgency in order to avoid the ultimate disasters that may results from the actual practice.

It was observed also that in the absence of an efficient and reliable public transportation while relying completely on the private vehicle, the country will not face only the roads traffic problems, but also a significant increase in the percentage of air pollution emitted from diesel and petrol engine. Moreover, the public transportation sector can benefits from the revolution of renewable energy and replace diesel or petrol by electric buses or vehicles that will help partially in the emissions reduction.

As an efficient and sustainable solution for the transport sector problems in Lebanon that will radically help the plan toward cleaner environment, we strongly recommend:

- ✓ Revitalization for the public transportation common service
- ✓ Applying more strict laws on the exaggerated number of imported cars that exceeds the capacity of the country in terms of road, emissions and costs
- ✓ Increasing the taxes and service fees on old cars responsible of the major amount of GHG emission.

A detailed study for the Energy efficiency in Lebanon that remains relatively modest despite the great potential for energy savings in all consumption sectors was realized. We have

observed that several temptations were done but still the country did not yet meet an acceptable level.

Energy Efficiency plan is highly recommended to be officially adopted in Lebanon, where mainly the country is facing a very important inflation for primary energy consumption since 2011, refugees' crisis, which affected the all of the country's economic activities.

During our study it was very surprising that in Lebanon the primary energy is consumed mainly in the form of final energy and shared between EDL (30%) and 70% for transport, residential, industrial, tertiary and agriculture sectors. Also it was noticed that transport and residential sectors are the main consumers with respectively 34% and 25% of the primary energy imported by the country. As well, it was detected a continuous grow in the consumption for household appliances particularly for the air conditioners. These trends strongly confirm the need to work on more efficient equipment at the household level but also to reduce these needs through better thermal insulation of buildings and more widely on urban cooling solutions.

With regard to the Electricity production sector in Lebanon, this matter has also his immense part of complications where two main sources, Electricité du Liban, (EDL: Public Sector) and Diesel generators (DG: private sector), are operating in parallel to fill the energy needs of citizens.

EDL, it is operating at 95% with Fuel oil while the DG work completely with diesel and both are a consistent source of air pollution in the country.

Concerning EDL, in order to reach an acceptable proper production, it needs rehabilitation, upgrading and shifting from fossil fuel combustion to a combination of production with renewable energy, thus we highly recommend the decision makers for this sector to:

- ✓ Start by reactivating the production from the hydraulic power plants since plants already exists and the country is considered very rich in water sources. However Lebanese government should not rely only on the hydraulic energy generation for clean production since this last cannot be an effective solution alone if we take into consideration the climate change in the last 3 decades in Lebanon where we are facing recently a random decreases in the rainfall.
- ✓ Activate the solar energy harvesting, a valuable and very effective renewable resource that can be capitalized easily in Lebanon since the country enjoys more than 3000 hours of sunshine during the year. Such a step for switching to solar energy required the

installation of photovoltaic farms on the national and individual planes, where governmental intervention is strongly needed at financial and technical levels at the beginning until the solar sector become auto-productive and satisfying in terms of Energy and finance.

- ✓ Modifying the present governmental laws concerning electricity production by allowing the individuals to sell the excess of energy produced by the renewable sources to the government (on grid solution), a pace that can has mutual benefits either on the economy or on the pollution reduction, environment protection and health advantage.

Regarding the Diesel Generators (DG), this trend has been introduced in the last 2 decades in Lebanon to cover the shortage of EDL in the electricity supply and the Lebanese consumers found themselves paying two bills for electricity where the DG's bill is double the public electricity's cost and the environmental impact is very harmful.

Both sources, EDL and DG, have a very high level of GHG emissions where the level of the CO₂ emissions per GDP in Lebanon is higher than the world average. Actually, the Lebanese power sector is responsible for 51% of the total GHG emission in the country and out of this 51% EDL is responsible for 32% the DG for 16%, whereas the rest through consumption fuel for cooking and heating.

In order to propose an efficient and applicable plan for the reduction of the dangerous effect caused by EDL and DG from the classical way of electricity production, we have explored the possibility of integrating a Micro-grid for residential uses. A ground study was done for the electric consumption of a set of Lebanese households and cover 4 seasons of the 2020-2021 years, using numerical analysis based on a real data measurement and allowed us to suggest some recommendations and solutions.

The numerical study permitted us to make a reliable comparison between the Diesel generators supply and the micro-grid, likely alternative clean sources, to verify the possibility of covering the shortage of the EDL. Obtained results showed clearly the benefit and advantages of switching to micro-grid energy production.

The necessity of this study comes from the fact that we are facing in Lebanon a brutal switching from fossil energy to green energy without a real estimation of costs and without taking into account several aspects such us investment, environmental damage, and consumption costs.

That's why we have aimed to establish an economic plan for energy production switching between Micro grid and fuel generator over 24 hours with given energy demand by the development and the optimization of analytical model considering simultaneously all these costs.

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