Performance Evaluation and Environmental Impact Assessment of Systems with Waste Exergy Emissions.

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(Only author names, for other information use the space provided at the bottom (left side) of first page or last page. Don't superscript numbers for authors)

Abstract— The transformation and utilization of non-renewable energies involves irreversibility which makes our system less efficient. The environmental impact potential is equivalent to the work potential of the emissions. The irreversibility of inefficient systems has Global Warming Potential or environmental impact potential as wasted exergy is not always in equilibrium with the environment. Most literatures have either considered the optimization of thermodynamic systems for better efficiency or environmental effect of the transformation and utilization of energy separately. Focusing more on systems with waste emissions, the exergy lost to the environment through their waste emissions have environmental impact potential. This work reviews literatures on exergy analysis done for systems with waste emissions (heat and gaseous) and some literatures on environmental impact of human activities like gas flaring. The work further proposes more research into the development of a system that would integrate the environmental impact Potential into the calculation of exergetic efficiency of any thermodynamic system. This is to put researchers on their feet to come up with systems that will be exergy efficient and environmentally friendly. Exergy analysis being a good Environmental Impact Indicator can be used to both optimize our systems and also reduce the pollution of our environment.

Index Terms — Waste Emission, Environmental Impact, Exergy, Fosssil Fuel, Irreversibility, Non-Renewable, Work potential.

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1   INTRODUCTION

Environmental problems span a continuously growing range of pollutants, hazards and ecosystem degradation factors that affect areas ranging from local through regional to global. Some of these problems may arise from observable, chronic effects on, for instance, human health, while others may stem from the perceived risk of a possible accidental release of hazardous materials [1]. Developments in industrial processes and structures have led to new environmental problems. For instance, in the energy sector, major increases in the transport of industrial goods and people by car has led to an increase in road traffic which has led to an increase in the attention paid to the effects and sources of NO_x and Volatile Organic Compound (VOC) emissions.

Fossil fuel depletion and global warming are two important concerns for the sustainability of energy systems in the future [2]. Human activities, mainly the burning of fossil fuels, and changes in land use and land cover, are increasing the atmospheric concentrations of greenhouse gases. The resulting enhanced greenhouse effect is likely to cause global warming and climate change. The atmospheric concentration of the most prevalent greenhouse gas, carbon dioxide (CO_2), has increased over 30% since the beginning of the industrial revolution and is continuing to increase [3].

2 ENERGY AND ENVIRONMENT

A significant number of these environmental issues are caused by or relate to the production, transformation and end use of energy [1]. For example, eleven major areas of environmental concern in which energy plays a significant role have been identified by international agencies [4], and include major environmental accidents, water pollution, maritime pollution, land use and siting impact, radiation and radioactivity, solid waste disposal, hazardous air pollutants, ambient air quality, acid deposition, stratospheric ozone depletion and global climate change [1].

Energy production, transformation, transport and use have important impacts on the earth's environment. Energy and environment policies increasingly play a prominent role in relating to a broad range of local, regional and global environmental concerns [5]. The interface between energy and the environment is complex and constantly evolving. Generally, the ability of science to identify and quantify the production and effects of potentially harmful substances has greatly advanced.

Demand for energy has been steadily rising despite limited availability of non-renewable fuel resources. Hence, efforts to develop more efficient energy systems are becoming increasingly significant [2]. Energy resources are required to supply the basic human needs of food, water, and shelter, and for improving the quality of life. It was indicated at the United Nations Conference on Environment and Development that it is crucial to consider the energy sector in any broad atmosphere strategy. The need was identified for two major areas of activity: programs to increase energy efficiency and programs to encourage the transition to environmentally sound energy systems. The major programs as accepted for consideration have objectives to promote:

(i) The energy transition;

(ii) Increased energy efficiency and, consequently, increased exergy efficiency;

(iii) Renewable energy sources; and

(iv) Sustainable transportation systems [6].

3 ENVIRONMENTAL CONTROLS

There is an increasing reliance on international approaches to global and trans-boundary environmental problems, using such means as international conventions and protocols. Improving and developing existing and future international coordination and harmonization efforts is a growing challenge for national and relevant international organizations. The balance that has to be achieved between the performance criteria of environmental acceptability on the one hand (environmental effectiveness, cost-effectiveness, equity and flexibility) and of energy security on the other (reliability, availability, adaptability and diversity) should now be considered at the international level as well as the national and individual polluters' level. It is imperative that all concerns, including energy interests, are represented in the process of development and implementation. Particularly important is identifying what has worked well in the past in developing and implementing coordinated, flexible and equitable approaches at the international level, especially where targets for emissions are considered [4].

Additionally, it was reported that (i) a major energy efficiency program would provide an important means of reducing CO_2 emissions, and (ii) these activities should be accompanied by strong new measures to reduce the fossil fuel components of the energy mix and develop alternative energy sources. These ideas have been reflected in many recent energy-related studies, which have concentrated on the provision of the energy service needed for an activity with the lowest environmental impact at the least cost and the maximum energy security possible [1]. Throughout the 1970s most environmental analyses and legal instruments of control focused on conventional pollutants, i.e. SO_x, NO_x, CO, and particulates. Recently, concern has been extended to the control of (i) hazardous air pollutants, which are usually toxic chemical substances, harmful in small doses and (ii) globally significant pollutants such as CO_2 [1].

4 EXERGY

Exergy is defined as the maximum amount of work which can be produced by a stream of matter, heat or work as it comes to equilibrium with a reference environment. Exergy is a measure of the potential of the system or flow to cause change, as a consequence of not being completely in stable equilibrium relative to the reference environment [4], [7], [8], [9], [10]. Ex-

ergy can be divided into four components: physical, chemical, kinetic and potential [2]. Kinetic and potential are usually neglected in most analysis. Physical exergy is the maximum work obtainable as a system interacts with an equilibrium state. Chemical exergy is associated with the departure of the chemical composition of a system from the chemical equilibrium of a reference environment. Chemical exergy is important in combustion evaluation [2].

Unlike energy, exergy is not subject to a conservation law (except for ideal or reversible processes). Rather, exergy is consumed or destroyed, due to irreversibilities in any real process. The exergy consumption during a process is proportional to the entropy created due to irreversibilities associated with the process [4], [7], [8], [9], [10].

There is, however, a considerable agreement among some researchers that a less-subjective metric capable of providing greater insight exist in the form of the thermodynamic quantity exergy. Owing to its origin within the thermodynamic community, to date a few researchers have investigated the potential of exergy within the framework of Design for Environment (DFE). Currently, the consortium on Green Design and Manufacturing at the University of California – Berkeley is carrying out a project entitled Exergy as an Environmental Indicator in an effort to bring about the practical application and adaptation of exergy analysis to the specific problems associated with the material and energy flows through industry [1], [9].

Data on the present world distribution of per capital energy consumption suggest that a close correlation exists between a country's energy consumption and economic development. However, there does not appear to be a simple correlation between a country's energy consumption and the decay of its natural environment [4]. Recently, several projects have been carried out at the Delft University of Technology and University of Twente to determine whether entropy or exergy analysis can be used as an instrument for environmental policy development, in particular for the comparison of alternative production chains [11].

4.1 Exergy models

Exergy is a measure of how far a certain system deviates from equilibrium with its environment and therefore, the following expressions can be written for exergy contained in a system.

$$Ex = T_0(S_{t,eq} - S_t) \tag{1}$$

where T_0 is the temperature of the environment and $(S_{t,eq} - S_t)$ is the deviation from equilibrium of the negentropy (=minus the entropy) of the system and its environment, i.e., the total system. ('eq' denotes equilibrium with the environment)

$$Ex = U + P_0V - T_0S - \Sigma_i\mu_{i0}n_i \tag{2}$$

where U, V, S and n_i denote extensive parameters of the system (energy, volume, entropy and the number of moles of dif-

ferent chemical components) P_0, T_0, and μ_0, are intensive parameters of the environment (pressure, temperature and chemical potential which also may include gravitational and electromagnetic potentials etc.) The subscript "0" denotes conditions of the reference environment. It is evident from this equation that the exergy of a system is zero when it is in equilibrium with the reference environment (i.e. when $T=T_0$, $P=P_0$ and $\mu_0=\mu$ for all k)

$$Ex = (U - U_{eq}) + P_0(V - V_{eq}) - T_0(S - S_{eq}) - \Sigma_i\mu_{i0}(n_i - n_{ieq}) \quad (3)$$

where, on the right side easily determined quantities appear. It is thus an easy task to determine the exergy content of a given environment. For a substance which has an exergy content deriving only from its concentration the following relation holds:

$$Ex = RT_0 n ln(c/c_0) \quad\quad\quad (4)$$

where n is the number of moles of the substance, R is the gas constant, T_0 is the temperature of the environment, c is concentration of the substance in the material considered, and c_0 = concentration of the substance in the environment.

For materials like inert gases or other not chemically active materials this concept of exergy is applicable. The chemically reacting materials receive an additional exergy contribution from the change in the chemical potential. The exergy content in a material can thus be summarized by the following formula:

$$Ex = n [\mu - \mu_0 + RT_0 ln(c/c_0)] \quad\quad\quad (5)$$

where μ_0 is chemical potential for the material in its reference state, i.e. in equilibrium with the environment. The chemical potential values for most materials can be found in a tabular form in some reference books [5].

4.2 Exergy and Environment

An understanding of the relations between exergy and the environment may reveal the fundamental patterns and forces that affect and underlie changes in the environment, and help researchers to deal better with environmental damage [5]. The increase in the global air temperature is an inadequate measure of global warming, which should rather be considered in terms of energy. The ongoing global warming means that heat has been accumulating since 1880 in the air, ground and water [12]. It is important to highlight that exergy analysis can lead to a substantially reduced rate in the use of natural resources and the environmental pollution by reducing the rate of discharge of waste products [5]. A method of quantifying environmental effects from energy consuming processes is to calculate the total exergy of waste streams [13].

Energy and environment studies that lead to increased energy efficiency can reduce environmental impact by reducing energy losses. Within the scope of exergy methods, such activities lead to increased exergy efficiency. In practice, the efficiency

improvements can be identified by means of modelling and computer simulation studies. Increased efficiency can often contribute in a major way to achieving energy security in an environmentally acceptable way by the direct reduction of emissions that might otherwise have occurred. Increased efficiency also reduces the requirement for new facilities for the production, transportation, transformation and distribution of the various energy forms; these additional facilities all carry some environmental impacts. To control environmental pollution, efficiency improvement actions often need to be supported by pollution control technologies or fuel substitution. It is through regional or national actions, rather than through individual projects, that improved exergy efficiency can have a major impact on environmental protection [1].

4.3 Exergetics and economics

Exergy measures the physical value of a natural resource (energy, material and information). Thus, it is also related to the economic value, which reflects the usefulness or utility of a resource. Exergy can be applied to both macro and microeconomics [14]. Thermo-economic accounting was developed by Gaggioli [15], Evans and Tribus [16] by assigning economic values to the exergy flows. When there are various in-and outflows, the prices may vary. If the price per exergy unit does not vary too much, we can define an "average price". This method allows comparison of the economic cost of the exergy losses of a system [14]. If we, by some reason, are not able to optimize the system, we may link cost to exergy by assuming a price of exergy, we call this exergy costing or thermo-economic accounting.

4.4 Exergetics and macroeconomics

In order to encourage the use of renewable resources and to improve the resource use, an exergy tax could be introduced. Inflow of non-renewable resources and waste should be taxed by the amount of exergy. By a conversion factor, which has to be decided, the exergy is converted into monetary units. In addition to this, restrictions may be applied against toxicity and irreversible environmental effects. To use exergy as base for tax has many advantages

- ✓ The exergy can be calculated from given physical data for the substance and the environment, which could be decided by international agreements.

- ✓ The exergy is related to the utility of the extracted deposit, and to its physical or environmental value, i.e., the physical "cost" to produce the resource from the environment.

- ✓ Exergy is a measure of the physical value of the environmental stress that is created from the exergy waste when it ends up as waste in the environment.

- ✓ Exergy is always a positive value when we have a distinction from the natural environment.

- ✓ Exergy also offers an excellent internal effciency concept to improve a system or process to meet these requirements in an optimal way.

- ✓ This tax should be governed by an international organization, e.g., the United Nations, since the effects usually are global [14].

4.5 Exergy destruction / losses

Exergy losses are divided into exergy dissipation and the exergy discharge loss. It is the last that affects the environment because accounts for the waste going directly to the environment. A system is polluting when its composition, concentration and state are different from those of the environment [13]. The primary contributors to exergy destruction are irreversibilities associated with chemical reaction, heat transfer, mixing and friction [17].

For real processes the exergy input E_{pr} always exceeds the exergy output E_{out}, this unbalance is due to irreversibilities, also named exergy destruction. The exergy output consists of the product E_{pr} and the waste, E_{waste}. Both exergy destruction and exergy waste represent exergy losses, but irreversibilities have, by definition, no exergy and, thus, no direct environmental effect. However, large exergy destruction may imply a large use of exergy input that may cause environmental damage. By calculating the exergy losses, possible process improvements may be visualized. In general, when the exergy loss is high, this part should be considered for improvement first. However, this 'tackle the biggest loss first' approach is not always appropriate. The reason is that every part of the system depends on each other, so that an improvement in one part may cause increased losses in other parts. The use of renewable and non-renewable resources must also be considered in a sustainability analysis. Therefore, the problem needs a more careful approach [18].

4.6 Exergy Analysis

Exergy analysis is a method that uses the conservation of mass and conservation of energy principles together with the Second Law of Thermodynamics for the analysis, design and improvement of energy and other systems [5]. The second law of thermodynamics stipulates that all macroscopic processes are irreversible. Every such irreversible process entails a non-recoverable loss of exergy, expressed as the product of the ambient temperature and the entropy generated (the sum of the values of the entropy increase for all the bodies taking part in the process). Some of the components of entropy generation can be negative, but the sum is always positive [19].

Significant attention has been directed towards the use of exergy analysis in the assessment of thermal and other industrial processes and their environmental impacts since exergy analysis is an effective tool both for achieving efficient energy utilization with minimum (or zero) environmental impact and for understanding environmental issues [1].

Studies are investigating if the linkages between entropy and the exergy with phenomena such as pollution and dispersion can be converted into a reliable tool on which policy decisions can be based, and are qualitatively exploring how the environmental effects of processes can be linked to or expressed in terms of entropy or exergy changes [20].

Thermodynamics which extends beyond the limits of energy-based analysis since exergy is generally not conserved as energy but is destroyed in the system. The exergy method assists the engineer in identifying the source and magnitude of performance loss in a thermal system by measuring the irreversibilities that occur in different devices and sections of the system [21].

Many engineers and scientists suggest that the thermodynamic performance of a process is best evaluated by performing an exergy analysis in addition to or in place of conventional energy analysis because exergy analysis appears to provide more insights and to be more useful in efficiency improvement efforts than energy analysis [5].

The exergy method can be suitable for furthering the goal of more efficient energy-resource use, for it enables the locations, type and true magnitudes of wastes and losses to be determined. Therefore, exergy analysis can reveal whether or not and by how much it is possible to design more efficient energy systems by reducing the sources of inefficiency in existing systems. Several researchers have suggested that the best way to link the second law and environmental impact is through exergy because it is a measure of the departure of the state of a system from that of the environment [22], [19].

In general, more meaningful efficiencies are evaluated with exergy analysis rather than energy analysis, since exergy efficiencies are always a measure of the approach to the ideal case [5]. For exergy analysis, the state of the reference environment, or the reference state, must be specified completely. This is commonly done by specifying the temperature, pressure and chemical composition of the reference environment [1]. The magnitude of the exergy of a system depends on the states of both the system and the environment. This departure is zero only when the system is in equilibrium with its environment. The concept of the environment as it applies to exergy analysis is discussed in detail in [23], [24], [25].

Performing exergy analyses of the natural processes occurring on the Earth could form a foundation for ecologically sound planning because it would indicate the disturbance caused by large-scale changes [26].

The depletion of non-renewable natural resources is very dangerous for the future development of humankind. The quality of these resources may be characterized in terms of their exergy. The author, therefore, introduced the concept of thermo-ecological cost, expressing the cumulative consumption of non-renewable exergy per unit of any product considered useful [27].

Also, some forms of energy (such as shaft work) are entropy-free, and thus entropy subtends only part of the energy field. Likewise, exergy subtends only part of the energy field as well since some systems (such as air at atmospheric conditions) possess energy but no exergy. Most thermodynamic systems (such as steam in a power plant) possess energy, entropy, and exergy, and thus appear at the intersection of these three fields [5].

The conclusion is that processes can occur only in the direction of increased overall entropy or molecular disorder. That is, the entire universe is getting more and more chaotic every day [5].

5 WASTE EMISSIONS AND ENVIRONMENTAL IMPACT

The exergy associated with process wastes emitted to the environment can be viewed as a potential for environmental damage. Typical process wastes have exergy, a potential to cause change, as a consequence of not being in stable equilibrium with the environment. When emitted to the environment, this exergy represents a potential to change the environment. In some cases, this exergy may cause a change perceived to be beneficial (e.g. the increased rate of growth of fish and plants near the cooling-water outlets from thermal power plants). More often, however, emitted exergy causes a change which is damaging to the environment (e.g. the deaths of fish and plants in some lakes due to the release of specific substances in stack gases as they react and come to equilibrium with the environment). Emissions of exergy to the environment can also interfere with the net input of exergy via solar radiation to the Earth. The carbon dioxide emitted in stack gases from many processes changes the atmospheric CO_2 content, affecting receiving and re-radiating of solar radiation by the Earth. The relation between waste exergy emissions and environmental damage has been recognized by several researchers [1].

Clearly, environmental costs are always associated with the emissions associated with the processes that give benefits to people. The environmental impact of emissions is normally reduced by increasing the efficiency of resource utilization, and by other energy conservation measures [20].

Goran wall found that CO_2 accounts for 99 wt% of all air emissions. Methane is emitted in the next highest quantity, 74% of which are fugitive emissions from natural gas production and distribution. Following CO_2 and CH_4, the next highest air emissions, in order of decreasing amount, include non-methane hydrocarbons (NMHCs), NO_x, SO_x, CO, particulates, and benzene [14].

5.1 Global Warming Potential (GWP) of Gaseous Emissions

The contributions from three greenhouse gases, CO_2, CH_4, and NO, are considered (Table 1 below) in the assessment of the Global Warming Potential (GWP) of the system [14].

TABLE 1

Emissions of Greenhouse Gases and Contribution to GWP

	Emissions amount (g/kWh)	Percent of greenhouse gases in this table (%)	GWP relative to CO_2 (100 year IPCC values)	GWP value (g CO_2-equivalent /kWh)	% contribution to GWP (%)
CO_2	439.7	99.4	1	439.7	88.1
CH_4	2.8	0.6	21	59.2	11.9
N_2O	0.00073	0.0002	310	0.2	0.04

The GWP of the system can also be divided among the different system operations. The table 2 shows the contribution of each subsystem to the overall GWP of the system. The power plant CO emissions contribute the most to the GWP at 64%. Because of the natural gas lost to the atmosphere, the natural gas production and distribution subsystem is responsible for nearly all of the remainder of the system s GWP [14].

TABLE 2

GWP CONTRIBUTION FOR EACH SYSTEM COMPONENT

Process step	GWP value (g CO_2-equivalent/kWh)	Percent contribution to GWP (%)
Power plant operation	372.2	74.6
Natural gas production & distribution	124.5	24.9
Construction & decommissioning	2.0	0.4
Ammonia production & distribution	0.4	0.1
Total	499.1	100.0

The construction and decommissioning subsystem includes power plant construction and decommissioning as well as construction of the natural gas pipeline [14].

5.2 Waste Emissions from Landfills

When organic materials decay in the absence of oxygen, carbon compounds are converted to the highly potent greenhouse gas methane, which has 21 times the warming potential (or Global Warming Potential, GWP) of carbon dioxide. Anae-

robic conditions exist in landfills and in parts of some wastewater treatment facilities. Consequently, these areas emit large amounts of methane, representing by far the greatest greenhouse impact of the waste management sector. Across the waste management sector, landfills emit much more methane than wastewater treatment plants [3].

The waste management sector also contributes smaller quantities of greenhouse gases through:

- ✓ fossil fuel energy use in the transport and processing of wastes

- ✓ trace emissions of potent greenhouse gases through the combustion of methane and biomass, and

- ✓ evaporative losses of non-methane volatile organic compounds from waste containing solvents.

5.3 Gas Flaring Emissions

Flaring is a high-temperature oxidation process used to burn combustible components, mostly hydrocarbons, of waste gases from industrial operations. Natural gas, propane, ethylene, propylene, butadiene and butane constitute more than 95% of the waste gases flared. The flared gas is the gas burnt off as unusable waste gas or flammable gas, which is released by pressure relief valves during unplanned over-pressuring of plant equipment. It burns through a gas flare (an elevated vertical chimney) on oil wells, in refineries, or in chemical plants. Gas flaring is hence as a result of oil exploration. Gas flaring is a common phenomenon in oil producing countries. Table 3 shows the top twenty gas flaring countries.

The molar composition of natural gas is given as 90.00% methane (CH_4), 4.63% ethane (C_2H_6), 3.91% propane (C_3H_8), 0.98% butane (C_4H_{10}) and 0.08% pentane (C_5H_{12}) excluding minor constituents.

There are a number of methods for handling waste gases at upstream oil and gas facilities, the most common being combustion. Flaring and incineration are two methods of combustion considered acceptable by the Energy Resources Conservation Board [29]. Flaring and incineration are two technologies used to combust waste gases that are unable to be processed or sold. Flaring is the igniting of natural gas at the end of a flare stack—a long metal tube up which the gas is sent. This causes the characteristic flame associated with flaring. Incineration is the mixing and combusting of waste gas streams, air, and fuel in an enclosed chamber. Air and gas are mixed at a controlled rate and ignited. No flame is visible from an incinerator that is operating properly [29].

In combustion, gaseous hydrocarbons react with atmospheric oxygen to form carbon dioxide (CO_2) and water. In some waste gases, carbon monoxide (CO) is the major combustible component. During a combustion reaction, several intermediate products are formed, and eventually, most of them are converted to CO_2 and water. Some quantities of stable intermediate products such as carbon monoxide, hydrogen, and hydrocarbons will escape as emissions. Gases flared in refineries, petroleum production, chemical industries, and to some extent from coke ovens, are composed largely of low molecular weight hydrocarbons with high heating value (HHV) [12].

TABLE 3
TOP TWENTY GAS FLARING COUNTRIES

2004 rank	Country	Reported Flaring 2004 (bcm)	2004 Rank	Country	Reported Flaring 2004 (bcm)
1	Nigeria	24.1	11	USA	2.8
2	Russia (total	14.7	12	Kazakhstan	2.7
3	Iran	13.3	13	Libya	2.5
4	Iraq	8.6	14	Azerbaijan	2.5
5	Angola	6.8	15	Mexico	1.6
6	Qatar	4.5	16	UK	1.6
7	Algeria	4.3	17	Brazil	1.5
8	Venezuela	3.7	18	Gabon	1.4
9	Equatorial guinea	3.6	19	Cameroun	1.1
10	Indonesia	3.5	20	Canada	1.0
	Total top 20	107.5			

Source: GGFR

The emissions depend upon a number of factors. Ultimately, combustion efficiency and heating value determines the types of emissions and environmental impact. For example, high efficiency combustion ensures that nearly all methane is converted to carbon dioxide (CO_2) and water vapour. If hydrogen sulphide (H_2S) is included in the waste gas stream, nearly all of the hydrogen sulphide is converted to sulphur dioxide (SO_2). If the waste gas stream contains both methane and H_2S, a lower combustion efficiency flare or incinerator may emit some H_2S and methane as unburned products. Lower efficiency combustion can also result in other emissions, including black smoke and particulates. Meanwhile, a correctly operated incinerator can yield higher efficiencies through proper mixing, gas composition, retention time, and combustion temperature. Properly designed incinerators can result in higher combustion efficiency than flares. However, incinerators can be

affected by a narrow range of flow rates compared to flares and therefore have difficulty adequately dispersing emissions with higher H_2S concentrations in the waste gas [29].

TABLE 4

Gas Flaring, 1870 – 2003

1870 – 2003	(1)	(2)	(3)	(4)
CO_2 gas flaring emission (Mt of C)	4569.61	4389.35	3609.94	3547.91
Gas flaring(m^3)	8.259×10^{12}	7.9333×10^{12}	6.5246×10^{12}	4125×10^{12}
Gas flaring (kJ)	3.226×10^{17}	3.009×10^{17}	2.549×10^{17}	2.505×10^{17}

It is widely acknowledged that flaring and venting of gas contribute significantly to greenhouse gas (GHG) emissions, with negative impacts on the environment. The table 4 shows the the total volume of gas flared between 1870 and 2003. The table also shows the energy lost as a result of the flare. The World Bank estimates that the annual amount of natural flared or vented (un-burnt) gas is equivalent to the combined annual gas consumption of Germany and France, twice the annual gas consumption of Africa, three quarters of Russian gas export, or enough to supply the entire world with gas for 20 days. This flaring is geographically concentrated: 10 countries account for 75% of emissions, and 20 for 90%. The largest flaring operations occur in the Niger Delta region of Nigeria [28].

Emissions from, e.g., the global use of fossil fuels and nuclear power, must contribute to global warming. The global net heat generation between 1880 and 2000 was found to be 45.3×10^{14} kWh, mainly resulting from of the global consumption of non-renewable energy. The total heat accumulation in air, ground, and water during the same period was estimated to 75.8×10^{14} kWh. That means that the global net heat generation explains 60% of the global warming, while 40% of the heat is missing. A considerable amount of this missing heat is hidden in the underestimation of global net heat generation [28].

The greatest source of error is that the net heat dissipation from fossil fuel only includes commercial energy consumption; that means oil, gas and coal used outside the energy market are not included in global energy statistics. Examples of such non-commercial energy are, for example flared and vented gas in oil fields, underground coal fires, peat fires, and petroleum products that is not used in energy production e.g. in the production of plastics. The amount of heat released from such sources is not available [28].

6 EXERGY ANALYSIS OF THERMODYNAMICS SYSTEMS WITH WASTE EMISSIONS

6.1 Exergy analysis of gas turbine

The power output of a gas turbine is claimed to increase as the

inlet air temperature decreases with an additional power consumption of 17.6% of the total power augmentation gained based on work done by Deng-Chen S. and Chia-Chin Chuang [30]. The power output is found to decrease with an air inlet temperature increase. Gas turbine output can be maintained nearly constant by controlling the inlet air for combustion to a specific condition. By installing the inlet air-cooling system, it is possible to provide maximum electrical power during hot summer days, when the demand on the Taiwan power grid is the highest [30].

Verkhivker and Kosoy pointed out the principal processes which cause the destruction of exergy in a power generation cycle are the combustion process, the subsequent heating of the working fluid and the heat transfer in the heat exchangers. Marrero et al. also confirms that the largest irreversibility is produced in the combustion process. It decreases with the increase of the gas Turbine Inlet Temperature (TIT) [31].

6.2 Exergy analysis of a 33-MW gas turbine

An exergy analysis of a 33-MW gas turbine power plant that operates on the Brayton cycle was done by D. P. S Abam and N. N. Moses [21]. Quantitative exergy analysis for each component and for the whole system was done. Based on the exergy balance, models developed, the performance of the power plant under varying ambient and turbine inlet temperature conditions shows that the largest amount of exergy destruction occurs in the combustion chamber and the least in the gas turbine. The simulation reveals remarkable dependency of the exergy flow rate of the power output, exergy efficiency, exergy destruction, heat-to-power ratio and the specific fuel consumption on the change in the ambient temperature and turbine inlet temperature of the plant [21].

Net exergy flow rates and exergy destruction in the gas turbine plant

TABLE 5
SUMMARY OF EXERGY ANALYSIS FOR A GAS TURBINE

Component	$\dot{E}w$ (MW)	$\dot{E}CHE$ (MW)	$\dot{E}T$ (MW)	$\dot{E}P$ (MW)	$\dot{E}D$ (MW)
Air Compressor	42.5290	0.0000	13.2241	24.9533	4.3515
Combustion Chamber	0.0000	116.8655	50.9338	0.6106	65.0313
Gas Turbine	72.7329	0.0000	47.4040	24.8762	0.4527
Plant	30.2	116.8655	16.7539	0.5335	69.8355
Exhaust	0.0000	0.0000	0.0000	0.0000	81.9193

The table 5 gives the exergy flow rates and exergy destruction in the gas turbine plant with the combustion chamber and the exhaust has the largest amount of exergy destruction.

6.3 Exergy analysis of a pulp and paper mill by mei gong [18]

Table 6 shows the main result of this study. The heating processes are highly exergy ineffcient. This is due to the fact that the thermal exergy of a system is often much lower than the thermal energy, particularly at temperatures close to ambient temperature. Waste water at a few degrees above ambient temperature has for all practical purposes almost no exergy value at all. However, for a local environment, it still could cause environment problem s due to its exergy content [15].

TABLE 6

SUMMARY OF EXERGY ANALYSIS OF PULP AND PAPER MILL

Process	Energy loss (%)	Exergy destruc-tion (%)	Exergy loss (%)
Debarking	2	2	2
Bark /oil boilers	6	13	13
Power plant	2	2	2
Digester	9	15	14
Washing screening	18	12	12
Evaporation plant	8	10	10
Recovery boiler	30	29	30
Causticizing	5	2	2
Bleaching	4	1	1
CTMP mill	5	7	7
Paper machine	11	7	7
Total	**100**	**100**	**100**

The least exergy efficient sub-processes are the recovery boilers and the bark/fuel oil boilers. These processes generate steam at an exergy efficiency of less than 35%. The main cause of this low efficiency is the irreversibility of combustion and of heat transfer in the steam generator due to the low temperature output. The difference in temperature between the combustion gases and the working fluid (water and steam) is very large. Thus, in principal, it is possible to add a process that utilizes this temperature difference.

Chemical energy is almost bound into the products, about 40% of the total inflow. Thus, most of the thermal energy that goes into the process ends up as waste heat. A large amount of the incoming exergy goes through the process without change, i.e. transit exergy. Chemical reactions, beside combustion, occur mainly in the digester [20].

6.4 Exergy analysis of a gasoline engine

In a comparative energy and exergy analyses of a four-cylinder, four-stroke spark-ignition engine in C. Sayin et al

[32], using gasoline fuels of three different research octane numbers (RONs), namely 91, 93 and 95.3. The study revealed that the combustion was the most important contributor to the system inefficiency, and almost all performance parameters increased with increasing engine speed [32].

Because combustion is strongly affected by the fuel properties, both the engine performance and exhaust emissions vary as functions of them. The effect of RON on the engine performance and /or exhaust emissions have been recently investigated by many researchers [33], [34], [35]. On the other hand, the effect of RON on detonation has also been studied [36, 37, and [38]. Abdulghani [20] found that as the octane number of the fuel increases the CO and HC emissions decrease but the NO_x emission increase [5].

The heat flow rate from the engine can be reduced by insulating the walls of the combustion chamber; this causes an increase in the temperature of the exhaust gas, thus increasing the energy loss due to the exhaust gas [39].

Although exhaust exergy loss is slightly lower than energy loss. The exergy loss can be decreased by reducing the exhaust gas temperature and the concentrations of CO and unburned HC in the exhaust gas. The rate of exergy destroyed within the engine is a function of engine speed and torque. Exergy is not conserved, and the irreversible processes in the engine, such as combustion, heat transfer, mixing, friction, etc., destroy a significant fraction of the fuel exergy. The rate of exergy destroyed in the engine increases with increasing octane rating and engine speed. The exergy destruction due to combustion can be reduced by taking some design precautions to increase the combustion temperature such as preheating the intake air and reducing the amount of excess air. However, these precautions may lead to an increase in the exhaust gas temperature, thereby causing a higher exergy loss accompanying the exhaust gas [32].

6.5 Exergoenvironmental Analysis of a Trigeneration System based on Micro Gas Turbine and organic Ranking Cycles

The trigeneration system consists of a gas turbine cycle, an organic ranking cycle (ORC), a single absorption chiller and a domestic water heater. The exergy efficiency of the trigeneration system is found to be higher than that of typical combined heat and power systems or gas turbine cycles. The exergy results show that combustion chamber has the largest exergy destruction of the cycle components, due to the irreversible nature of its chemical reactions and the high temperature difference between the working fluid and flame temperature. The parametric investigations show that the compressor pressure ratio, the gas turbine inlet temperature and the gas turbine isentropic efficiency significantly affect the exergy efficiency and environmental impact of the trigeneration system. Also increasing the turbine inelt temperature decreases the cost of environmental impact, primarily by reducing the combustion chamber mass flow rate [2].

6.6 Gasification Process

Gasification is the conversion of the hydrocarbon contained in a solid fuel into combustible gas. In addition to the fuel, air or oxygen and steam are supplied to a gasifier. The result is a product gas that is in most gasification processes rich in hydrogen H_2 and carbon monoxide CO. in addition, the product gas contains carbon dioxide CO_2, steam H_2O and some methane CH_4.

The main source of thermodynamic inefficiencies in a gasifier are the chemical reactions. Heating of inert chemical components, mixing of streams with differences in temperature, pressure and chemical composition as well as pressure drop due to friction also contribute to the exergy destruction. With increasing gasification temperature, both the relative amount of combustion and the required internal heat transfer in the gasifier increase; thus, the exergy destruction within the gasifier increases. For a given carbon conversion ratio, the exergy destruction in an adiabatic gasifier can be reduced by preheating the reactants and by reducing the temperature of the syngas at the outlet [17].

6.7 Steam reforming process

Steam reforming is a catalytic conversion of hydrocarbon and steam by an endothermic reaction with steam into hydrogen H_2 and carbon monoxide CO.

The main endothermic inefficiencies in the reformer are associated with the chemical reactions (steam reforming and combustion) and heat transfer from the combustion products to the hydrocarbon/water mixture in the tubes. The exergy destruction caused by the combustion reaction is significantly higher than the exergy destruction due to the reforming reaction. The exergy destruction associated with the reforming reaction can be reduced by preheating the hydrocarbon and the steam and by mixing the reactants at equal temperature and pressure. Friction and heat losses also contribute to the thermodynamic inefficiencies [17].

7 EXERGY ANALYSIS OF MORE EXERGETIC EFFICIENT SYSTEMS

7.1 Exergy Analysis of a Coke Dry Quenching System

Coke Dry Quenching (CDQ) process has been successfully applied in the No.3 coke oven plant of China Steel Corporation for the purposes of energy saving as well as sustainable CO_2 reduction. To get more insight into the energy utilization efficiency of the CDQ system, the exergy analysis methodology based on the first and second laws of thermodynamics was proposed Pei-hsun Lin et al., and the exergy balance analysis for the CDQ system was conducted under the normal operating conditions. The analysis results indicated that the irreversibility for the CDQ system was 66,056 MJ/h under the normal operating conditions, implying that 414 MJ of exergy was destroyed for each ton of coke extinguished. Furthermore, the exergy efficiency of the CDQ system was 65.6%, whereas its energy efficiency was 85.2%. The gap between energy and exergy efficiencies of 19.6% implied that the process internal losses and the interaction between the CDQ system and the environment played an important role in usable energy transformation process. With the combined operation of the CDQ system and the cogeneration plant, an annual energy saving of 8.8 million US dollars and a CO_2 reduction of 144,415 ton/year have been achieved [40].

7.2 Exergy Analysis Of Gas-Turbine Combined Cycle With CO_2 Capture Using Pre-Combustion Decarbonization Of Natural Gas by Hanne et al., 2002 [41]

An energy and exergy analysis of a power-plant with decarbonisation of NG by auto-thermal reforming and pre-combustion CO_2 removal was investigated by Hanne et al 2002. It was shown that heating the reforming process by oxidation within the auto-thermal reformer is favourable to preheating the reformer feed by supplementary firing (SF) in the gas-turbine exhaust. The exhaust gas can provide enough heat for reformer preheating without SF. Moreover, an increasing amount of fuel to SF increased the total irreversibility, and hence, reduced the net output from the plant. This was due to the higher irreversibility caused by SF compared to that of the two other main reactors, the gas-turbine combustor and the auto-thermal reforming reactor. Increasing the gas-turbine pressure ratio may improve the performance of conventional combined-cycle processes. This resulted from a reduced-steam-cycle irreversibility due to reduced turbine-exhaust temperature. However, this was not the case for the process with NG reforming and CO_2 capture. It was shown that at a certain turbine inlet temperature (TIT), a higher pressure-ratio gave a slight reduction of the net efficiency. This resulted from an increased irreversibility of the reforming process, in particular that of the auto-thermal reforming reactor [41].

8 GLOBAL NET HEAT GENERATION

The major natural heat source is geothermal heat flow, but heat is also generated by volcanic eruptions, earthquakes and meteorites, among others. Non-natural heat sources include the global use of fossil fuels, nuclear power and deforestation. Heat emissions from nuclear bomb tests and conventional bombs also add to the net heat generation [12].

8.1 Geothermal heat flow

The compiled mean geothermal heat flow [42] is 0.065 Wm^{-2} for the continents and 0.101 Wm^{-2} for the oceans. Its variation is a result of the composition and thickness of the upper part of the crust. The total geothermal heat flow during the last 120 years is 486×10^{14} kWh (175×10^{21} J). This energy is considerably greater than the global energy consumption during the same period and is given as a reference value to other net heat sources, though it does not contribute to global warming [12].

8.2 Volcanoes and earthquakes

The energy released through volcanic eruptions comes from several sources, though the most significant (and the one considered here) is the thermal energy of volcanic eruptions. Based on the number and magnitudes of eruptions [43], the thermal energy released from a few large volcanic eruptions during the last 120 years was estimated to 3.95×10^{14} kWh. An average of 1.4 million earthquakes occurs each year on Earth. Most are small and disregarded, while larger earthquakes with a magnitude of 8–9 are included in this net heat calculation. The energy released in an earthquake is given by the Gutenberg-Richter [44] magnitude-energy relation. The United States Geological Survey Frequency of Occurrence of Earthquakes was used to estimate the total energy dissipation (2.7×10^{14} kWh). A few earthquakes occurring once a century or so would result in greater heat emissions than all others combined. Such quakes are not included here, but must be considered in similar studies on geological timescales.

8.3 Nuclear bomb tests and conventional bombs

More than 2000 nuclear tests, atmospheric and underground, were carried out in 1945–1998. Though nuclear explosions have a great power, the released energy was small because of its short duration. The performed nuclear tests [45] released a total of 6.64×10^{12} kWh of heat. The energy released by conventional bombs was also investigated. The bombs and weapons used during the Second World War released a net heat of 6.7×10^9 kWh. The corresponding value for the Gulf War was 9.8×10^7 kWh. Therefore, wars do not directly mean any significant net heating, though their consequences do. During the Gulf War, 700 oil wells were set on fire and 190 Mm^3 of oil burned for 8 months [46]. This meant that 1.9×10^{12} kWh of heat was added to the atmosphere. It is estimated that 10^{13} kWh of energy was released by the bombs in all the wars [47] during the last 120 years.

8.4 Commercial energy

The world's consumption of commercial non-renewable energy from 1880 to 2000 has been steadily increasing and was smaller than the preceding years, only in 1975 and 1981. The use of renewable energy has also increased, though it represents less than 5% of the world's energy consumption.

The total commercial energy consumption from 1880–2000 is 38.5×10^{14} kWh (13.9×10^{21} J). All this energy dissipates into heat when consumed and must contribute to the heating of our planet. A useful key value is that the global energy consumption in 2000 was approximately 10^{14} kWh (0.36×10^{21} J).

8.5 Non-commercial fossil fuel consumption

The fossil fuel consumed outside the energy market is not included in the global energy statistics. Examples of such non-commercial energy are flares at gas and oil fields, fires at coal fields and underground fires in coal mines and petroleum products that are not used in energy production, e.g., in the production of plastics. Deforestation and the amount of heat released from such sources were evaluated by Gervet [28]. This reference also contains working material used to determine other net heat sources.

8.6 Gas flaring

The flaring of associated gas was a common industry practice in the early 'decades' of oil production, when there were virtually no gas markets or concerns regarding the environment or the rational use of hydrocarbon resources. Gas flaring in Africa alone is presently equivalent to half of that continent's power consumption. Fewer than 20 countries account for more than 85% of gas flaring and venting. The magnitude of this problem is underlined by the World Bank's The News Flare [48], which is devoted to reducing global gas flaring. The energy released by gas flaring during the last 120 years approximately corresponds to the annual global energy consumption in 1999, i.e., 0.9×10^{14} kWh.

8.7 Underground coal fires

Hundreds of coal fields are burning out of control around the world. Some of the oldest and largest coal fires occur in China, the USA and India. In China alone, such fires annually consume 20 metric tonnes of coal [49]. Those burning underground can be difficult to locate and are not included in this net heat estimation. Fires in coal fields worldwide consume 1307 million tonnes of coal that emits 8.8×10^{12} kWh of heat. Another net heat source is oil used for the production of plastics. This oil, which is not included in the energy statistics, will sooner or later be burnt or decomposed. The net heat generation from the use of crude oil in plastic making is roughly 0.4×10^{14} kWh from 1939 to 2000.

8.8 Deforestation

The annual deforestation rate is 200 km^2 since 2000, before which it was even greater. Most of the deforestation occurs in tropical forests, mainly in Africa. Since 1850, 11.1 Mkm^2 has been deforested, totalling 282 800 million tonnes of wood. Assuming that the deforested wood were burnt or decomposed, the net heat generation since 1880 has been 8.2×10^{14} kWh.

8.9 Nuclear power

Until 2000, the accumulated amount of electricity produced by nuclear power is approximately 0.4×10^{14} kWh. Since 78% of the world's nuclear park has an efficiency of 33%, the resulting heat emission from nuclear power plants is 0.8×10^{14} kWh. Waste heat from nuclear power plants means a very small share of the total heat emissions, but locally, it means a large impact on the recipient. As an example, Sweden's nuclear power plants generate 70 TWh of electricity, which consequently means that 140 TWh of waste heat is produced and dumped into the sea water. This amount of heat is 40% greater than the annual space heating demand of all buildings in Sweden. It is also a fact that algae blooming in Swedish coastal waters occur where this waste heat is dumped. This algae

blooming is generally blamed on global warming and this is most likely true, since waste heat is part of the problem [42].

CONCLUSION

The irreversibility of thermodynamic system during the transformation and utilization of non-renewable energy resources makes our systems less efficient and have negative environmental impact potential.

Emissions from thermodynamic systems are usually through the exhaust, which are gaseous wastes and heat waste released into the atmosphere. Each of these emissions has a potential impact on the environment. The release of emissions by our systems is tantamount to the release of exergy into the environment, which not only limit the efficiency of the system and waste our resources, but also contribute to the Global Warming of our planet.

Wasted exergy is released by a system that is not in thermodynamic equilibrium with the environment. This means the physical, chemical, kinetic and potential exergy of the system is different from that of the environment. No additional release of exergy into the environment has positive environmental impact potential. It is either a Global Warming Potential or a source of pollution to the atmosphere. It is therefore important using exergy analysis to evaluate the environmental impact potential of systems and improve the performance of the systems through reduction of waste emissions.

The emission of wastes to the environment increases the chaos in the world by allowing the constrained material and heat products of combustion to be released without constraint into the environment.[1] Attention therefore has to be shifted from the use of non-renewable energy resources to the renewable energy resources. This is due to the negative effect of the exploitation of the non-renewable in terms of energy degradation during use and negative environmental impact potential.

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