Thermo-Ecological analysis of Recovery of LNG cryogenic exergy by electricity production

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Energy Engineering and Management

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Nomenclature

B – exergy, kJ
$\dot{B}$ – exergy flow, kW
B* - exergy cost, kW
b – specific exergy, kJ/kg
p – pressure, bar
T – temperature, K
S – entropy, kj/K
F – exergy of “fuel”
P – exergy of “product”
I – irreversibility
δB – exergy loss, kJ
E – energy, kJ
k – exergy cost
$\dot{E}$ – energy stream, kW
$\dot{m}$ – substance stream, kg/s
h - specific enthalpy, kJ/kg
i – specific enthalpy, kJ/kg
s – specific entropy, kJ/(kg*K)
η_B – exergy efficiency
η_E – energy efficiency
L – work, kJ

List of abbreviations

CCGT – Combined Cycle Gas Turbine

LNG – Liquified Natural Gas

HRSG – Heat Recovery Steam Generator

GT – Gas Turbine

ST – Steam Turbine

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Abstract

Natural gas is a fossil fuel with the highest growth dynamics in the global energy mix. The transport of gas in liquefied form (LNG) is an alternative to traditional pipelines. The gas liquefaction process is very energy intensive. Part of the energy used in this process is stored in LNG as cryogenic exergy. In a conventional regasification process, this exergy is lost by release into seawater or another factor serving as an external heat source. There are many concepts for the use of LNG cryogenic exergy. Among possible applications to use LNG for the production of electricity are: using it as the lower heat source in thermodynamic cycles or directly as a working fluid.

As part of this work, two technological systems have been modeled: simple CCGT power plant and CCGT plant integrated with LNG regasification. Both cycles were subjected to a deep analysis by the means of exergy and thermoeconomic analysis. Special algorithm (so-called matrix method) for exergy cost calculations and diagnosis has been tested. The method proved to be a perfect tool for analyzing even complex cycles. However it was found that the algorithm cannot cope with exergy diagnosis for systems where fluid temperature is crossing the ambient temperature as it requires unambiguous and binary exergy sinks and sources (fuel and product) definition. Suggestions were included in the work to improve the method to work for any system.

Key words: LNG, exergy, CCGT, regasification, energy recovery, thermoeconomic analysis

Resumo

O gás natural é o combustível fóssil com maior crescimento dinâmico no conjunto global de energia. O transporte do gás na sua forma líquida (GNL) é uma alternativa às tradicionais condutas. O processo de liquefação do gás é muito intensivo do ponto de vista energético. Parte da energia utilizada neste processo é armazenada no GNL como exergia criogénica. Num processo de regaseificação convencional, esta exergia é desperdiçada pela libertação na água do mar ou por outro fator que serve como fonte de calor externa. Existem muitos conceitos para a utilização da exergia criogénica do GNL. Entre as aplicações possíveis para a utilização do GNL para a produção de eletricidade podemos: usá-lo como fonte fria nos ciclos termodinâmicos ou diretamente como fluido de trabalho.

Como parte deste trabalho, dois sistemas tecnológicos foram modelados: uma simples central de CCGT ou uma central CCGT integrada com a regaseificação de GNL. Ambos os ciclos foram sujeitos a uma análise profunda no âmbito da exergia e análise termoeconómica. Para o cálculo e diagnóstico do custo de exergia foi testado um algoritmo especial chamado o método da matriz. Este método provou ser a ferramenta de análise perfeita até para ciclos complexos. No entanto, foi descoberto que o algoritmo não se consegue aliar com o diagnóstico de exergia para sistemas onde a temperatura do fluido transita a temperatura ambiente, pois requere definições de fontes frias e fontes quentes (combustível e produto) de exergia binários e não ambíguos. Algumas sugestões foram incluídas no trabalho para melhorar o método de trabalho de qualquer sistema.

Palavras-chave: GNL, exergia, CCGT, regaseificação, recuperação de energia, análise termoeconómica

1. Introduction

1.1. Motivation

Modern trends show a dynamic growth of natural gas share in world energy mix. Natural gas used to be transported in gaseous state by pipelines or gas tankers but within last two decades rapid growth of an alternative way of transportation has emerged – LNG (Liquified Natural Gas). LNG demand is expected to continue growing.

Natural gas and LNG consequently are being chosen as an energy source thanks to their easy and cost-effective technologies for transforming it into heat or work as well as balanced environmental impact. However, there is no technology which is free of imperfections and energy losses, even though many engineers and scientists have spent their lives improving it. It implies a need for constant development.

Main focus in the dissertation is put on thermoeconomic analysis and employing so-called matrix method for this. The matrix method is a not widely known tool, however it offers opportunities for analysing very complex (multi-component) systems in time shorter than standard analysis. The motivation for the thesis was to promote the method and to test how it copes with atypical cycle – Combined Cycle Gas Turbine integrated with LNG regasification.

Additionally, the idea for the diploma was to compare two cycles: one classic CCGT (Combined Cycle Gas Turbine) and second CCGT integrated with LNG regasification by the means of their thermodynamic performance.

1.2. Objectives and scope of work

The aim of the work is to verify potential of proposed solution for electricity production and minimization of exergy and energy losses. Another goal of the work is to conduct analyses of proposed solutions by the means of exergy and thermoeconomic analysis. The diploma aimed at conducting a thermoeconomic analysis of an exemplary CCGT plant and subsequently analysis of a selected CCGT plant integrated with LNG regasification. The calculation algorithm for this diagnosis was based on a matrix method that allows an easy and transparent way to analyse even very complex systems. This method will be presented and explained what will allow to clearly understand the issues discussed. As part of the calculations, the following software was used: Thermoflex 26 [1], CoolProp [2], REFPROP [3], Microsoft Excel.

The scope of the analysis includes:

- Generating a mathematical model of a selected combined cycle gas turbine plant using the Thermoflow's package, Thermoflex 26 [1] program, the aim of which is to obtain thermodynamic parameters such as temperature, pressure, mass streams, as well as exhaust gas composition and degrees of dryness at selected points of a cycle, for selected operational states.
- Creating an algorithm for calculating the value of exergy for each stream of the analysed circulation, in separate operational states. This was done with the help of the Excel, CoolProp [2] and REFPROP [3] databases. First, the thermodynamic values obtained from the Thermoflex 26 [1] program were imported, and then the values of enthalpy, entropy and, finally, exergy were determined.
- Conducting a thermoeconomic analysis based on a matrix method, using a Microsoft Excel spreadsheet.

1.3. Organization of the thesis

The thesis is divided into two main parts: Theoretical and Computational. The first part, which consists of chapters 2 to 4, presents a basic piece of information about Liquified Natural Gas, Exergy and Exergy cost analysis. The chapter on LNG explains the nature of LNG as well as technologies related which serve to its processing (liquification and regasification). Moreover, concept of exergy recovery is mentioned, followed by LNG market outlook by the means of its import and export. Chapter on exergy explains basic theoretical background essential for understanding the concept of exergy. Finally, chapter 4 focuses on exergy cost analysis which is a tool for gaining additional knowledge on thermodynamic imperfections and their real sources in the process in comparison to standard energy analysis.

In the second part, which consists of chapters 5 to 7, a complex thermoeconomic analysis is conducted for a Combined Cycle Gas Turbine power plant and the same plant expanded by integrating it with LNG regasification. Chapter 7 presents comparison of two plants by the means of general performance.

Finally, chapter 8 summarizes whole dissertation, aggregates single results and puts some final conclusions.

2. Liquified Natural Gas

2.1. LNG as a way of natural gas transportation

The traditional method of natural gas transport used for over a century is a pipeline transport. Gas pipelines constitute a stable and safe source of natural gas supplies from large, conveniently located deposits of this fuel. As the old deposits were depleted and new being found far away from customers, it became necessary to develop alternative methods for natural gas transportation.

Under normal conditions, 1 m^3 of methane has a mass of 0.66 kg and a calorific value of 32.8 MJ. For comparison, 1 m^3 of crude oil has a mass of about 835 kg and a calorific value of about 41 GJ, which is more than a thousand times higher than gas methane. Due to the low energy density, it would be unreasonable to transport methane in tankers or cisterns. The only natural gas alternative to pipelines that has developed on a commercial scale is liquefied natural gas (LNG) [4].

Methane with a temperature of -162 °C under normal pressure is colourless, odourless, non-toxic and non-corrosive with a density of approximately 650 times higher than in normal conditions. The condensation of methane allows, therefore, to increase the energy density to about 21 GJ per cubic meter. After delivery of LNG to the destination, it is regasified to the gas form. The advantage of transporting natural gas in the form of LNG is its flexibility. The natural gas supplier is not rigidly connected to the customer through the pipeline. Liquefied gas can be delivered by sea to any regasification terminal in the world. In this way, LNG contributes to increasing competitiveness on the natural gas market. The gas recipient who has the regasification terminal can freely choose from whom he will buy the fuel.

Figure 1 presents cost comparison of natural gas transportation by pipelines and LNG. Liquified natural gas becomes more profitable as a way of transportation for long-distance transport. As is appears from Figure 1, for short distances, gas pipelines are usually more economical. LNG is competitive for long-distances, especially when the need to cross the ocean appears, as undersea pipelines are cost consuming. For offshore pipeline, LNG can be competitive when the distance is less than 700 miles while for onshore pipelines, the breakeven point is about 2,200 miles [4].

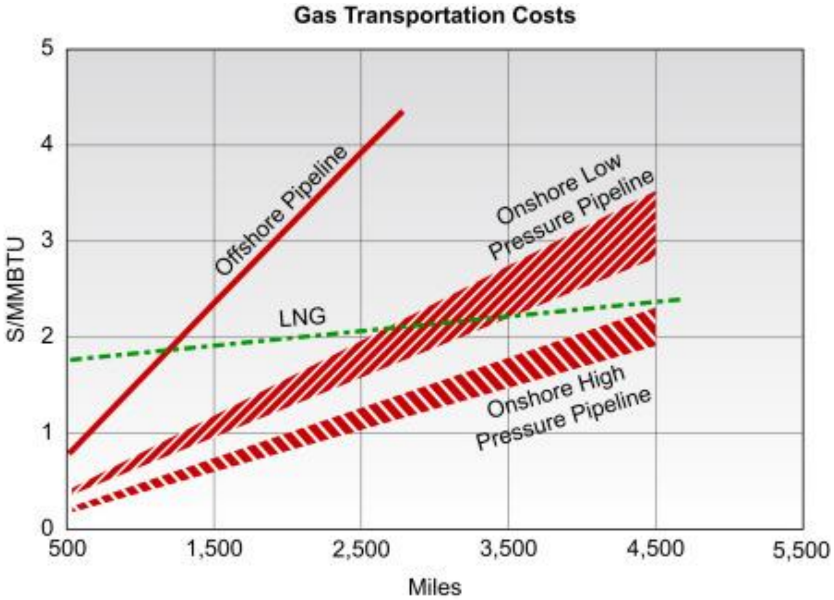


Figure 1 Comparison of the cost of transporting gas via pipeline and LNG; for 1 trillion cubic feet/year and including regasification costs [4]

The LNG production and supply chain are shown schematically in Figure 2. It consists of four main stages: natural gas extraction, purification and liquefaction, transportation and regasification.

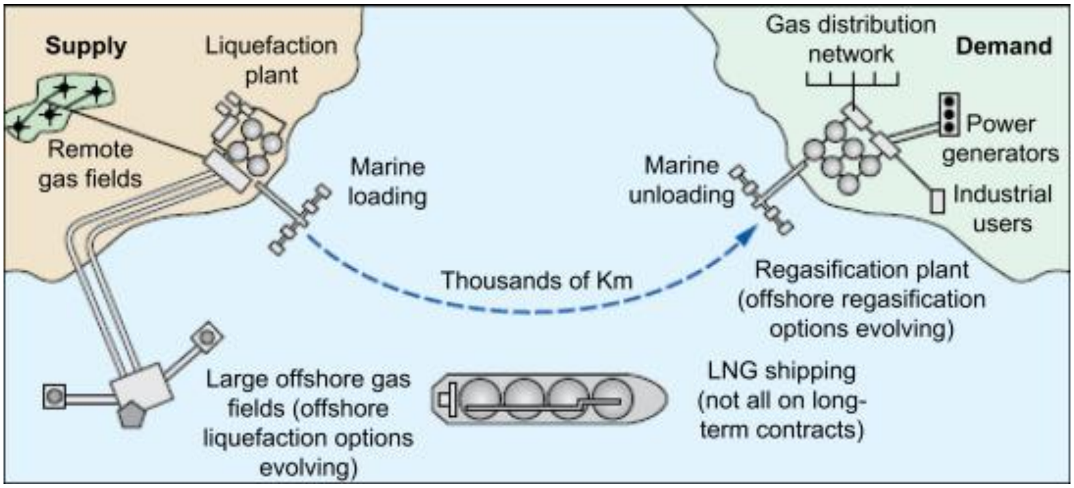


Figure 2 Diagram of the LNG production and supply chain [4]

2.2. Natural gas liquification

Before natural gas liquefaction, it must be cleaned of undesirable components. The raw material supplied from the gas field is first separated into a gaseous and liquid fraction. Then the gas passes several stages of purification. The first stage is the removal of carbon dioxide and sulfur compounds by amine methods. The CO_2 content is reduced to 50 ppm, H_2S content to 4 ppm. In the next stage, molecular sieves absorb moisture and other sulfur compounds. The moisture content of the dried gas is less than 0.1 ppm and the total sulfur content (hydrogen sulphide, mercaptans and sulphur monoxide) should not exceed 30 ppm. If natural gas contains mercury, it must also be removed. The concentration of mercury should be lower than 10 ng/m^3. Requirements regarding the maximum concentrations of the substances listed above result both from the trade specifications of natural gas and from the harmful effects of these substances on the structural elements of natural gas pipelines and tanks. The last stage before gas condensation is the separation of hydrocarbons heavier than methane. These compounds would cause operational problems in the condensation process. Ethane may or may not be separated. In addition, propane, butane and higher hydrocarbons can be sold separately at a higher profit than if they remained in the LNG. During the liquefaction of natural gas, nitrogen is additionally removed from it [5].

The most energy-consuming process in the LNG production chain is gas liquefaction. Condensing technology is based on the principle of refrigeration cycles. The natural gas must be cooled to the saturation temperature, which is approximately -160 °C at normal pressure. Existing liquefaction technologies are based on three basic methods [4, 5, 6]:

- Classic cascade cycle. Natural gas is cooled in several subsequent refrigeration cycles in which the refrigerants are propane, ethane and methane. Parameters of the cooling cycles are selected to get the best possible approximation of temperature profiles of condensed gas and refrigerant. The advantages of this method include relative energy efficiency and technological simplicity. The disadvantages are the substantial number of equipment machines resulting in high investment costs and the demand for pure ethane and propane.
- A cycle with a mixed refrigerant. The refrigerant is a mixture of hydrocarbons selected so that its temperature profile is as close as possible to the temperature profile of condensed natural gas. This method is slightly more energy-intensive than the classic cascade cycle, but its advantage is the smaller number of compressors and heat exchangers. It is characterized by a longer start-up time than the cascade method.
- Expansion cycle using a turboexpander. It uses the Joule Thomson effect. In this process, part of the gas undergoes expansion, which results in cooling to a very low temperature. The cooled gas is then used to condense another portion of gas flowing through the installation. This method is relatively simple and does not require large capital expenditures but is more energy-intensive than cascade and mixed refrigerant methods. For this reason, it is used in small condensing installations and for covering peak demand for the capacity of a condensing unit.

The most popular method of liquefying natural gas is the AP-C3MR (*Air Products propane precooled mixed refrigerant*) process, based on a mixed refrigerant method. Natural gas is pre-cooled with propane in this method. In 2015, this process and its modifications accounted for 79% of the global LNG production capacity. 14% covered the ConocoPhillips Optimized Cascade method, i.e. a process with cascade cooling cycles [7].

Condensing 1 kg of natural gas requires an average consumption of 1.2 MJ of energy for liquification. This demand for energy is covered by burning about 8% of the natural gas supplied to the LNG factory [4]. Part of the energy used in the liquefaction of natural gas is stored in LNG as cryogenic exergy. This exergy can be partially recovered in the regasification process. The definition of exergy is contained in chapter 3.

2.3. LNG regasification

The task of the regasification terminal is to bring the LNG into the gas state and inject it under the required pressure to the network of transmission pipelines. LNG discharged from ships is first sent to insulated tanks, where it is stored under a slight overpressure at a temperature several degrees below the evaporation temperature. LNG evaporates in them in an amount of about 0.05% volume per day. For this reason, the regasification terminal should be equipped with a BOG condensation installation or maintain minimum send-out. The LNG taken from the tank is first compressed to the pressure required in the receiving gas pipeline. This is dictated by the fact that the work of compressing the liquid is much lower than the work of compressing the gas at the same pressure ratio. The compressed LNG goes to a heat exchanger in which it is vaporized and heated to a temperature close to ambient temperature. Because of the heat source the regasification method selected by LNG can be divided into the following groups [4]:

- ORV (Open Rack Vaporizers), STV (Shell and Tube Vaporizers) - heat needed for LNG evaporation is taken from seawater. The ORV and STV methods differ by a design solution for a heat exchanger. These are the most popular regasification methods, used in over 70% of regasification terminals. Because the terminals are most often located on the coasts, seawater is cheap source of heat available in massive quantities. Regasification systems of this type are simple to construct, safe, easy to maintain and have low operating costs. However, they require frequent maintenance due to the pollution of the heat exchange surface by sediments present in seawater. The applicability of this regasification method is determined by the climatic and environmental conditions near the terminal. The composition of sea water should be examined. Too high content of heavy metals affects the accelerated corrosion of heat exchangers, while the excessive content of solid sediments implies the need to thoroughly filter the water. If the seawater temperature is too low, it cannot be used as a source of heat. It is assumed that the water temperature should not be lower than 5 °C, and the temperature drop of the water consumed should not exceed 5 K. In the cold climatic zone, using the ORV method may not be possible for a whole year. Also, environmental contraindications related to marine flora and fauna sensitivity may occur for reduced water temperature.

- AAV (Ambient Air Vaporizers) - the heat needed for LNG evaporation is taken from atmospheric air. The AAV method is more environmentally friendly than the ORV method and its use is not limited by the ambient temperature. However, due to the small coefficient in comparison to the ORV method heat transfer requires a much larger surface of exchangers, which results in large area occupancy. For this reason, the AAV method is not optimal for terminals with a large designed regasification capacity. The main exploitation problem of this method is icing the surface of exchangers, therefore every 4 to 8 hours ice accumulated should be removed. An additional problem, especially in a humid climate, may be the formation of a fog restricting visibility near the terminal.
- SCV (Submerged Combustion Vaporizers) - the heat needed to evaporate LNG comes from the combustion of part of the vaporized gas. It is the second most popular regasification method, used in about 20% of terminals. Due to high operating costs (fuel consumption is about 1.5% of regasified LNG), this process is used only where no other, free heat sources are available. The regasification exchanger is placed in a tank with water on the bottom of which there are burners. The fumes in the form of bubbles migrate upwards, sweeping the heat exchange surface and ensuring good heat transfer conditions. The exhaust gases are cooled to low temperatures and the moisture contained in them is condensed, increasing the energy efficiency of the process, which reaches over 98 %. Thanks to the large heat capacity of the water, this system copes well with LNG flux changes and is able to provide heat for some time after switching off the burners. The operational problem is the acidic reaction of the water bath caused by the exhaust components dissolved in it. Excess acids should be neutralized to prevent corrosion. Another problem may be the formation of nitrogen oxides during the combustion of natural gas.
- IFV (Intermediate Fluid Vaporizers) - an intermediary agent circulates in a closed circuit, and the heat needed for regasification can come from the environment or from another industrial process (e.g. waste heat from a power plant). The most commonly used circulating agents are aqueous glycol solutions and liquid hydrocarbons. The intermediary agent may additionally work in the clockwise thermodynamic cycle (e.g. Rankine cycle) and drive the turbine, thus producing electrical energy.

2.4. LNG exergy recovery

In conventional regasification processes, all cryogenic exergy stored in LNG is transferred into seawater or other factor serving as an external heat source and lost. However, it can be partially recovered. The profitability of the "cold" recovery of exergy must in any case be subject to thermodynamic and economic analyzes, but the use of these technologies always leads to a reduction in energy intensity of cumulative LNG import as well as related CO_2 emissions.

There are many concepts for the use of LNG cryogenic exergy. They can be divided into two groups. The methods of the first group are based on the direct use of low LNG temperature. Among the possible applications are: condensation and air separation, food industry (food cooling or freezing), air conditioning, cryogenic desalination of seawater or utilization in various industrial processes, e.g. in petrochemistry [8]. Low temperature LNG can also be used for cooling condensers in Rankine cycle-based plants or for cooling compressed air in gas turbine cycles. The second group of methods is based on the use of LNG cryogenic exergy for the production of electricity. Liquefied natural gas can be used as the lower heat source in thermodynamic cycles or directly as a circulating medium. Most common methods are [9]:

- Direct expansion cycle (DEC),
- Rankine cycle (RC),
- Brayton cycle (BC),
- Kalina cycle,
- Stirling engines.

In the thesis a hybrid model of direct expansion cycle has been analyzed. The cycle is further explained in the subchapter 6.1.

2.5. LNG import and export

Figure 3 shows the LNG export volumes by all 18 countries that in 2017 participated in the global LNG market on the suppliers' side. The biggest exporter of LNG has been Qatar for several years, which satisfies almost one third of the global demand for this fuel.

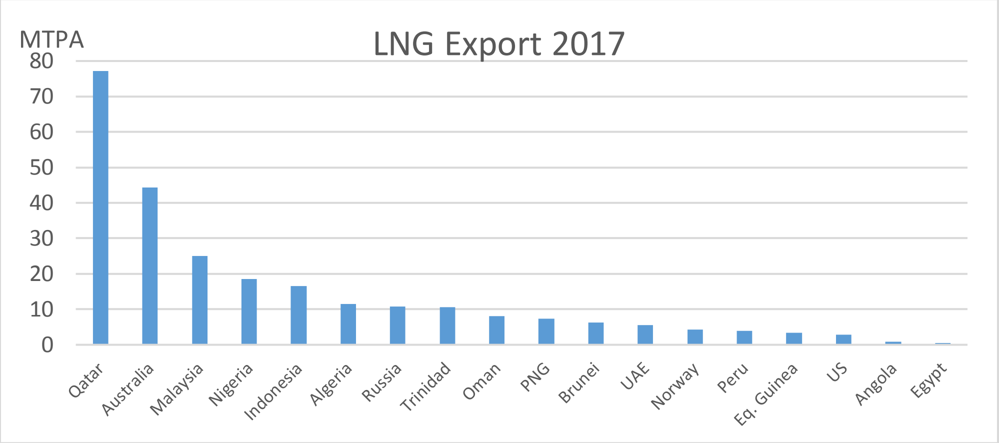


Figure 3 Global LNG Export in 2017 [7]

In 2017, 35 countries participated in the global LNG market on the recipients' side. Figure 4 presents the volumes of LNG imports by individual countries. The largest importer is Japan, which provides up to one third of global demand for this fuel. In Europe, the largest LNG importers are United Kingdom and Spain. The figure does not include imports less than 2.5 MT which are (by order of size): Singapore, US, Portugal, Puerto Rico Belgium, Malaysia, Brazil, Lithuania, Poland, Dominican Republic, Greece, Netherlands, Israel, Canada, Jamaica and Colombia.

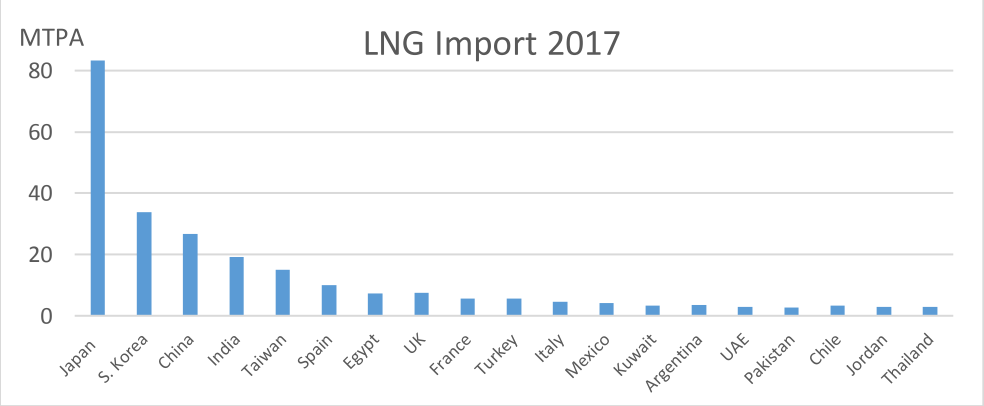


Figure 4 Global LNG Import in 2017 [7]

3. Exergy

3.1. Definition of exergy

The concept of energy is not a sufficient criterion to describe the practical utility of its various carriers, as evidenced by the fact that streams of compressed and not compressed air, having the same temperature, transport the same amount of energy due to the fact that the enthalpy of air depends a little from a pressure. Therefore, the concept of exergy has its origin in the second law of thermodynamics, according to which each thermodynamic change proceeds towards increasing entropy, and thus it is accompanied by losses associated with the irreversibility of the process. As a result, it became possible to characterize different energy carriers in terms of quality, not only quantitative, because exergy determines the ability to transform different forms of energy into other ones. It is important that the practical energy usefulness of matter is equal to zero when it is reduced to a state of thermodynamic equilibrium with the surrounding nature. Thus, the surrounding nature is a kind of zero point - a reference in the exergy analysis [10].

Finally, the following definitions of exergy were adopted:

- *Exergy is the amount of work obtainable when some matter is brought to a state of thermodynamic equilibrium with the common components of the natural surroundings by means of reversible processes [11].*
- *The minimum work needed to raise system from the reference state to the system state* [11].

The total exergy of the substance stream consists of: B_k kinetic exergy, B_p potential exergy, B_f physical exergy, B_{ch} chemical exergy, B_j nuclear exergy, other exergy components.

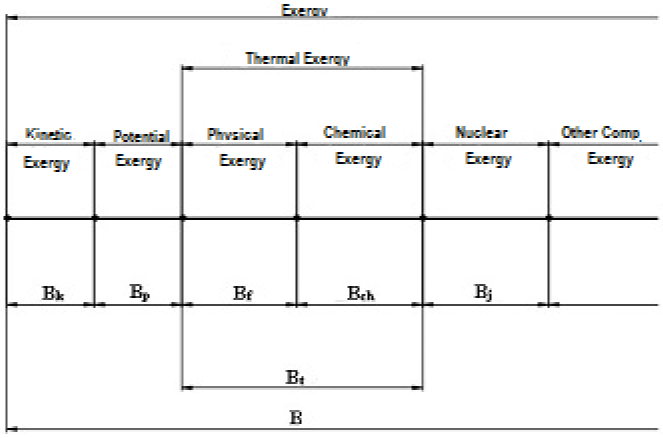


Figure 5 Exergy components of the substance stream [11]

The physical exergy is zero if the substance has an ambient temperature as well as ambient pressure. However, when a substance with these parameters has a chemical composition that is not compatible with the composition of bodies commonly found in the environment, the substance is characterized by a non-zero and usually a positive value of chemical exergy. The inclusion of chemical exergy is necessary in the case of analysis of processes during which the substance is exchanged with the environment [11].

3.2. The balance of exergy losses

In the surrounding nature, the well-known energy conservation law is universally applicable. With regard to the concept of exergy, however, the law of conservation is no longer applicable due to the fact that all thermodynamic changes are accompanied by irreversible changes, represented by the so-called exergy losses. The total amount of energy does not change, but it is devalued, which means that it loses its practical utility. The loss of exergy caused by the irreversibility of a given phenomenon is determined by the Gouy - Stodola law, which is given by the equation (1):

$$\dot{B} = \mathrm{T}_0 \sum \dot{S} \tag{1}$$

where:
$\dot{B}$ – internal losses of exergy,
T_0 – ambient temperature,
$\dot{S}$ – increase in entropy of the system

This law, also called exergy destruction, is in a way contrary to the law of conservation of energy. The loss of exergy determined for a given device is the sum of exergy losses that accompany a given thermodynamic process. In addition, these losses cannot be partially recovered. They reduce the useful product or increase the consumption of a fuel. Goya - Stodola's law is a good diagnosis tool, because it allows to detect the reasons for the decreasing perfection of the thermal process, and also allows the separation of exergy losses according to the reasons for their occurrence. These losses are divided into internal ones, resulting from the irreversibility of thermodynamic changes occurring within the considered device and external ones, caused by bringing into the environment a thermodynamic medium with positive exergy, i.e. one that has components that have different parameters than the commonly occurring components of the environment. It is important to achieve the optimum between exergy losses occurring in the system and the economic factor related to the reduction of these losses as any reduction of process imperfections results in an increase in the investment expenditure for a given installation [11].

Despite the fact that the exergy balance, unlike the energy one, does not fulfil the *law of energy preservation*, it became possible to form an equation, which is closed by introducing a quantity representing the internal losses of exergy. This value is the difference between the exergy derived and introduced to the analysed system [11].

$$\mathrm{B}_{in} = \Delta\mathrm{B}_{sys} + \mathrm{B}_{\mathrm{out}} + \mathrm{L} + \sum \Delta\mathrm{B}_{\mathrm{source}} + \delta\mathrm{B}_{\mathrm{in-int}} \tag{2}$$

$$\mathrm{B}_{\mathrm{out}} = \mathrm{B}_{\mathrm{out\ waste}} + \mathrm{B}_{\mathrm{out\ useful}} = \delta\mathrm{B}_{\mathrm{ext}} + \mathrm{B}_{\mathrm{out\ useful}} \tag{3}$$

The above formulas (2) and (3) present the exergy balance, where:
B_{in} – exergy of factors brought into the system,
$\Delta\mathrm{B}_{\mathrm{sys}}$ – increase in system exergy,
$\mathrm{B}_{\mathrm{out}}$ – exergy of factors leaving the system,
$\mathrm{B}_{\mathrm{out\ useful}}$ – useful exergy of derived products,
$\mathrm{B}_{\mathrm{out\ waste}}$ – waste exergy of derived products,
$\delta\mathrm{B}_{\mathrm{ext}}$ – external losses of exergy,
L – work done by the system,
$\Delta\mathrm{B}_{\mathrm{source}}$ – increase in exergy of the external heat source in contact with the system,
$\delta\mathrm{B}_{\mathrm{in-int}}$ – internal loss of exergy caused by irreversible changes inside the system.

Figure 6 shows the so-called Grassmann diagram representing the band graph of the exergy balance. The darkened area represents, respectively, the internal losses of exergy resulting from the irreversibility of transformations as well as the external losses of exergy caused by the discharge into the environment of substances with parameters and composition differing from the environment. As it can be noticed, exergy derived from the system is divided into useful and waste exergy which constitute the discussed external losses [11].

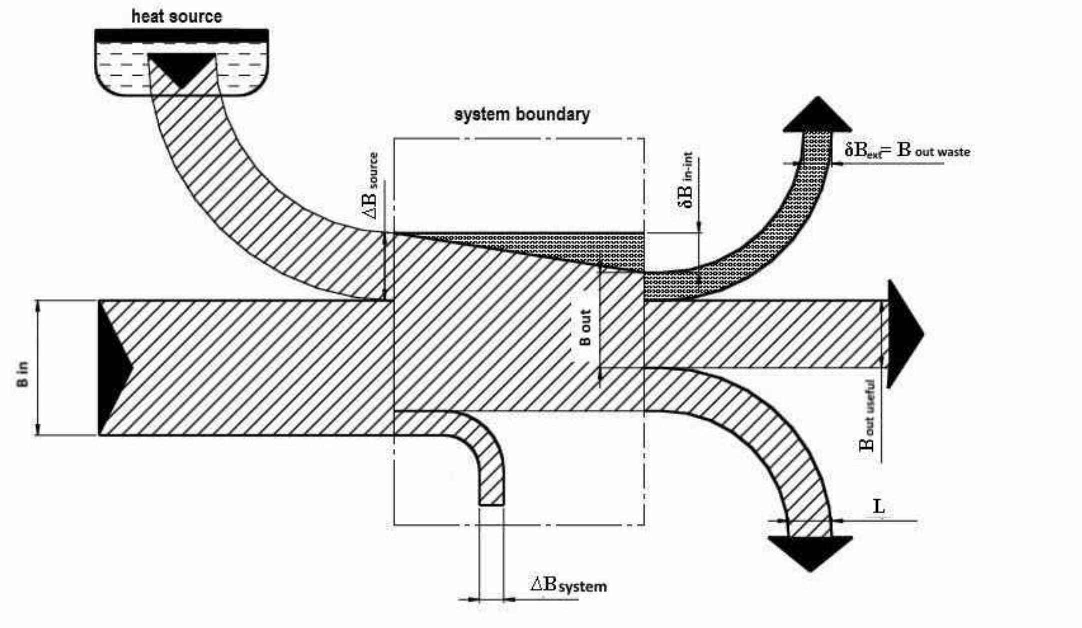


Figure 6 Grassmann diagram of exergy balance [11]

Exergy balance is also the basis for determining exergy efficiency, expressing the ratio of useful exergy to fuel exergy, which is given by the formula (4):

$$\eta_B = \frac{B_{\text{useful}} - B_{\text{sn}} + L_{\text{useful}} + E_{\text{el useful}} + \Delta B_{\text{source useful}} + \Delta B_{\text{sys useful}}}{B_N + L_N + E_{\text{el N}} - \Delta B_{\text{source N}}} \tag{4}$$

where:

B_{useful} – useful exergy of useful process products,
B_{sn} – exergy of non-energy raw materials,
L_{useful} – useful work obtained in the process,
$E_{\text{el useful}}$ – useful electricity obtained in the process,
$\Delta B_{\text{source useful}}$ – increase in exergy of external heat sources,
$\Delta B_{\text{sys useful}}$ – useful increase of system exergy,
B_N – exergy of drive substances (eg fuels),
L_N – driving work,
$E_{\text{el N}}$ – driving electric power,
$\Delta B_{\text{source N}}$ – decrease in exergy of the external heat source.

3.3. Calculation of exergy

As in the case of energy, the exergy can be divided into the internal relating matter within system boundary, and the flow leaving the system boundary. From a practical point of view, flow exergy is more important because most of the analysed devices are flow-through. Flow exergy can be divided into several components as shown in equation (5), which include: kinetic exergy, potential exergy and thermal exergy, which in turn is divided into physical and chemical parts as shown in equation (6) [12].

$$\dot{B} = \dot{m}\left(\frac{c^2}{2} + g \cdot H + b_t\right) \tag{5}$$

$$b_t = b_f + b_{ch} \tag{6}$$

where:
$\dot{B}$ – exergy flow,
$\dot{m}$ – substance stream,
c – the speed of the substance stream against the Earth's surface,
g – gravitational acceleration of the Earth,
H – height of the centre of the stream over the assumed level of the environment,
b_t – specific thermal exergy,
b_f – specific physical exergy,
b_{ch} – specific chemical exergy.

Based on the formula (6), it can be seen that kinetic and potential exergy are equal to kinetic and potential energy. In practice, when analysing thermal and flow processes, the kinetic and potential exergy is omitted, considering only physical and chemical exergy [12].

Physical exergy expresses a decrease of exergy in a situation when the tested substance differing in temperature and pressure in relation to environmental parameters will be reduced to these parameters. The physical exergy is given by the formula number (7) [12]:

$$b_f = i - i_0 - T_0(s - s_0) = i_f - T_0 s_f \tag{7}$$

where:
b_f – specific physical exergy,
i_f – specific physical enthalpy determined for ambient parameters,
i_0 – specific physical enthalpy determined for ambient parameters,
s_f – specific physical entropy determined for ambient parameters,
s_0 – specific physical entropy determined for ambient parameters,
T_0 – ambient temperature.

The physical exergy can be divided into a temperature part and a pressure part in the considered parameter range. However, this applies to substances that are not subject to phase changes during a given process. The temperature section is always positive, because cooling the substance to a temperature below the ambient temperature increases the value of the exergy.

On the contrary, the situation is to the pressure part of the exergy. If the pressure of the considered substance is lower than the ambient pressure, then the pressure part of the physical exergy has then a negative sign, because the introduction of the substance to pressure below ambient requires the consumption of the driving exergy [12].

Chemical exergy refers to a substance whose temperature and pressure have values corresponding to the environment, whereas its composition differs from commonly accepted reference substances. The reference state of chemical exergy should result from the condition of chemical equilibrium with the surrounding natural environment. However, it is not possible to achieve a chemical equilibrium with a system that is not in equilibrium, therefore the reference substance is assumed to be different for each of the chemical elements. As reference substances for chemical exergy were adopted the components dominating in atmospheric air, solid substances occurring at the surface of the land, as well as ions and particles dissolved in sea waters. In addition, apart from taking a reference substance, it becomes necessary to determine their concentration in the environment [12]. By treating the analysed substance as a perfect gas containing only components of the atmospheric air, the chemical exergy can be expressed by the formulas (8),(9) [11]:

$$b_{ch} = T_0 \sum_i g_i R_i \ln \frac{z_i}{z_{i\,ot}} \tag{8}$$

$$(Mb)_{ch} = T_0 (MR) \sum_i z_i \ln \frac{z_i}{z_{i\,ot}} \tag{9}$$

where:
b_{ch} – specific chemical exergy,
$(Mb)_{ch}$ – molar specific chemical exergy,
(MR) – universal gas constant,
R_i – individual gas constant of the component of the given substance,
g_i – gram fraction of the component of the substance in question,
z_i – molar fraction of the component of the substance in question,
$z_{i\,ot}$ – the molar fraction of the component in the ambient atmospheric air,
T_0 – ambient temperature.

The chemical exergy of the reference substance is zero, in the reference state. However, there are numerous substances in the surrounding nature whose exergy is positive. These substances are natural resources, which are fuels for many industrial processes. The exergy of a given fuel is determined in a certain approximation based on its calorific value, or the heat of combustion, as well as the proportionality coefficient as presented in formula (10) [11]:

$$b_{ch} = a \cdot W_d = b \cdot W_g \tag{10}$$

where:
b_{ch} – chemical exergy of fuel,
W_d – lower heating value,
W_g – higher heating value (heat of combustion),
a, b – proportionality factors.

Table 1 presents the coefficients used to determine the chemical exergy of a given type of fuel based on the calorific value or the heat of combustion.

Table 1 Ratio of normal chemical exergy of fuel in relation to calorific value - a and heat of combustion - b [12]

Fuel	a	b
Hard coal	1.09	1.03
Lignite	1.17	1.04
Coke	1.06	1.04
Wood	1.15	1.05
Liquid fuels	1.07	0.99
Natural gas	1.04	0.94
Coke oven gas	1.00	0.85
Blast furnace gas	0.98	0.97

To sum up, the main purpose of applying exergy analysis is to assess the degree of imperfection of the processes under consideration, as well as to locate the causes and magnitude of their impact on the increase of this imperfection. In addition, this analysis takes into account the undesirable effects of processes such as throttling, diffusion and heat transfer at finite temperature difference, which is not included in the energy balance. Exergy is also a valuable tool to assess the influence of thermal parameters on the economic value of energy carriers as mentioned before. It should be remembered, however, that exergy is still a thermodynamic, not an economic analysis.

Table 2 presents a comparison of characteristic energy and exergy features.

Table 2 Comparison of characteristic energy and exergy traits [13]

Energy	**Exergy**
- It is subject to the law of preservation.	- It is not subject to the law of preservation.
- It has conventional reference levels.	- It has reference levels imposed by the surrounding nature.
- It increases as the temperature rises.	- At ambient pressure and ambient temperature, its value is equal to zero.
	- It increases when temperature decreases below ambient.
- In the case of perfect and semi-perfect gases, value of enthalpy does not depend on the pressure.	- It depends on the pressure.
- For perfect vacuum it is equal to zero.	- It has a positive value for a perfectly empty tank, placed in a non-vacuum environment.

4. Exergy cost analysis

4.1. Exergetic cost

The basis for carrying out the thermoeconomic analysis, which is the purpose of this work is to determine the so-called exergy cost. It happens that many things considered valuable due to the material value of a given product are thermodynamically deprived of this value. The source of value may or may not be related to the amount of exergy contained, also in the case of fuels. It is therefore necessary to estimate the cost of the product, understood as the amount of energy units needed to produce a useful product. However, the problem of energy is related to the problem resulting from the lack of effective techniques for allocating a specific energy content when two products are produced simultaneously. A much more precise solution in this aspect has become the concept of exergy, distinguishing energy carriers in terms of their ability to perform work [13].

Determining the exergy cost allows to check how the individual components of a separate system work and interact with each other. This gives information about what losses are generated in devices, and how these imperfections affect the work of others. Thanks to this, it is possible to determine if the changes in operation have a beneficial or negative effect on the operation of the devices and how these changes affect the imperfection of the processes occurring in the separate components of the system. It may happen that as a result of changes a given component has improved its performance, thus causing deterioration of working conditions in another. One should therefore strive for a state in which the losses of exergy during particular stages of the production process are minimized. However, it is not possible to strive at all costs to reduce these imperfections, as limiting losses should go hand in hand with measurable financial benefits.

The calculation of the consumption of exergy in the selected component is connected with the necessity to create an exergy balance and to determine the exergy efficiency of the device.

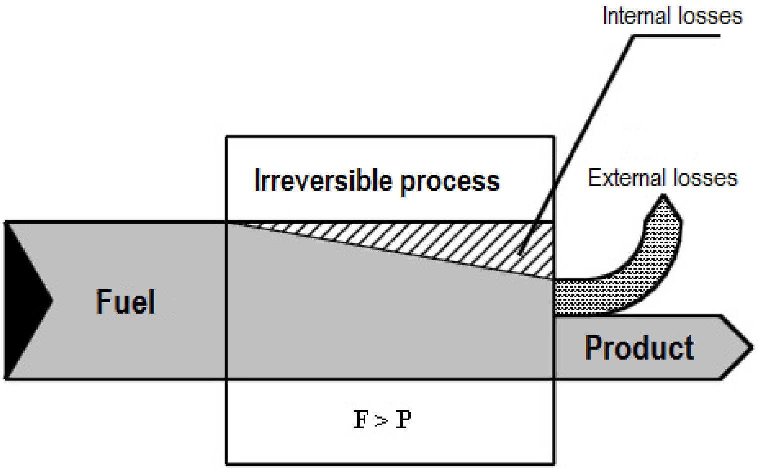


Figure 7 Exergy balance for the component [14]

Exergy efficiency and specific exergy cost of the highlighted component are given by the formulas (11), (12):

$$\eta_B = \frac{\dot{B}_P}{\dot{B}_F} \leq 1 \quad (11)$$

$$\mathrm{k_B} = \frac{1}{\eta_\mathrm{B}} = \frac{\dot{\mathrm{B}}_\mathrm{F}}{\dot{\mathrm{B}}_\mathrm{P}} \geq 1 \tag{12}$$

where:
η_B – exergy efficiency,
$\mathrm{k_B}$ – specific exergy cost,
$\dot{\mathrm{B}}_\mathrm{F}$ – exergy brought to a given component (fuel),
$\dot{\mathrm{B}}_\mathrm{P}$ – exergy derived from a given component (product).

It should be remembered that exergy efficiency due to the irreversibility of the process, which is represented by internal losses of exergy, is always less or equal to one. The situation changes in the case of a specific exergy cost, which is the reciprocal of exergy efficiency. Therefore, the value of the specific exergy cost is greater than or equal to one.

In the case of a chosen technological cycle, we usually deal with many components. Then, the exergy cost is formed - it is generated at individual stages of the manufacturing process, as shown in the diagram Figure 8 below. Analysing large energy systems, it is necessary to know how the exergy cost increases in individual components of the system. Thanks to this, it is possible to check what connections the various devices have with each other, and thus their particular participation in the process of exergy cost formation. Figure 8 shows a diagram of the formation of exergy costs in the thermodynamic chain of the production process.

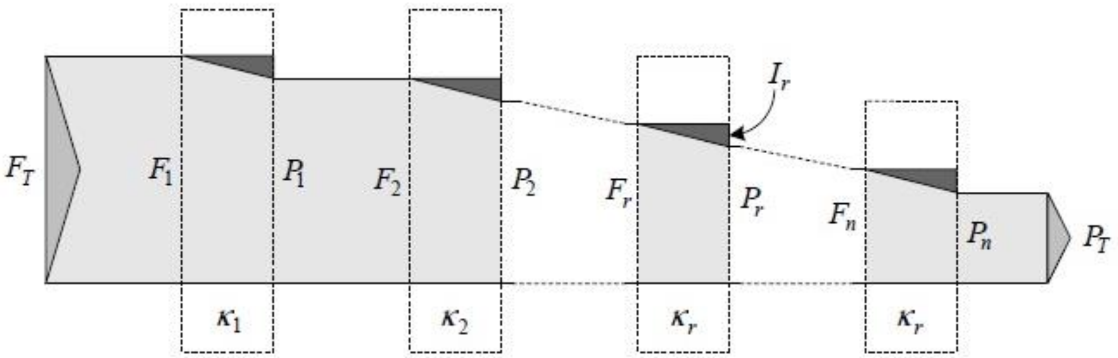


Figure 8 Exergy balance for the component [13]

According to Figure 8, one can write formulas (13), (14), (15):

$$\mathrm{k}_1^* = \frac{\mathrm{F_T}}{\mathrm{P_1}} < \mathrm{k}_2^* < \mathrm{k}_\mathrm{r}^* < \mathrm{k}_\mathrm{n}^* \tag{13}$$

$$\mathrm{k}_\mathrm{r}^* = \frac{\mathrm{F_T}}{\mathrm{P_r}} \tag{14}$$

$$\mathrm{k}_\mathrm{n}^* = \frac{\mathrm{F_T}}{\mathrm{P_n}} \tag{15}$$

where:
k_1^* – exergy cost of the 1st stream,
k_2^* – exergy cost of the 2nd stream,
k_r^* – exergy cost of the r-th stream,
k_n^* – exergy cost of the n-th stream,
$\mathrm{F_i}$ – exergy of fuel supplied to the i-th component,
$\mathrm{P_i}$ – exergy of the product derived from the i-th component.

For each component of the extracted system it is true to say that the exergy of supplied fuel streams is greater than the exergy flows of products by the difference in the irreversibility of thermodynamic conversion. Therefore, in order to obtain a certain amount of usable product, it is necessary to supply a sufficiently large amount of fuel. It should be noted that every loss of exergy occurring in individual components accumulates, influencing the increase in exergy of the fuel supplied. Finally, as a result of the generated losses throughout the cycle, the final product is burdened with an increasing exergy cost as shown in equation (16) [13].

$$\mathrm{F} - \mathrm{P} = \mathrm{I} > 0 \tag{16}$$

In the case of a sequential system, where the process product is at the same time the fuel for the next one, the cost of the exergy for this process should be recorded as in equation (17) [13]:

$$\mathrm{P}_\mathrm{i}^* = \mathrm{P}_\mathrm{i} + \sum_{1}^{\mathrm{i}} \mathrm{I}_\mathrm{r} \tag{17}$$

where:
I_r – irreversibility of transformation in a given component.

On the other hand, it can be noted that the specific exergy cost of the product is equal to the specific consumption of exergy of all components involved in the process what can be written as in equation (18) [13]:

$$\mathrm{k}_{\mathrm{p,i}}^* = \prod_{\mathrm{r}}^{\mathrm{i}} \mathrm{k}_\mathrm{r} \tag{18}$$

The thermoeconomic analysis is best carried out based on the so-called matrix method. Thanks to it, it becomes possible to carry out diagnosis of even very complicated systems, which in the case of this work applies to the simple CCGT Plant and CCGT Plant integrated with LNG regasification. This method is based on the creation of adequate exergy balances and determination of losses in individual places of the system using pre-defined matrices representing flows of individual streams between components. For this purpose, it is necessary first and foremost to isolate the analysed system by covering it with a system boundary, which allows to say what streams reach the analysed system from the environment, and which ones emerge from it. Then it is important that each component is defined by assigning the appropriate number to it. The same applies to streams feeding and leaving given components. These streams are usually divided into fuels F supplying selected devices and P products, i.e. streams on which the work was performed. It should be remembered that the products of one component can be a fuel for another, which generates a kind of network of interrelations between the devices of the system. Therefore, it is necessary to record the exergy flows, which will inform about the flow direction. For example, the record $\dot{\mathrm{B}}_{\mathrm{ij}}$ says that the exergy flow $\dot{\mathrm{B}}$ leaves the "i" component as a product, thus feeding the "j" component as fuel. The numbering method itself is also not accidental, because it should be started with "1" starting from the production components, such as a fuel compressor, ending with dissipative devices - giving energy out of the system boundary, and thus to the environment as in the case of a condenser. The number "0" means the so-called environmental component representing the environment, but in the analysis, it is omitted due to the fact that exergy flows characterized by environmental parameters have a value equal to zero.

In Figure 9 way of fuel delivery to the i-th component is shown:

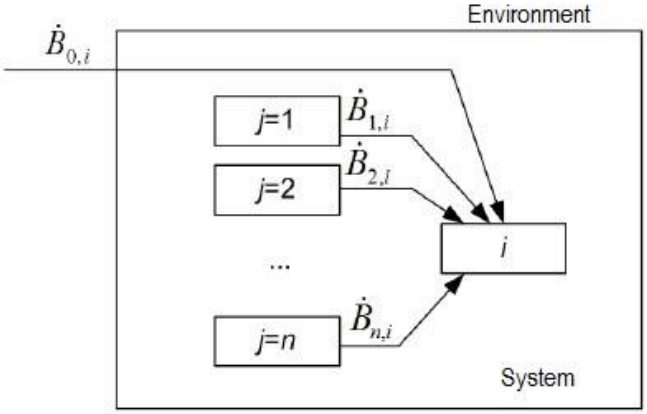


Figure 9 The method of fuel supply to the i-th component of the extracted system [15]

In turn, the total fuel supplied to the i-th component is calculated according to the formula number (19), thus adding up all the partial fuels.

$$F_i = B_{0,i} + \sum_{j=1}^{n} B_{j,i} \tag{19}$$

where:

F_i – total exergy of fuel feeding the i-th component,

$B_{0,i}$ – exergy of the stream delivered to the i-th component from the environment,

$B_{j,i}$ – exergy of the stream supplied to the i-component from the j-th component,

n – component number.

The situation is similar to the exergy flows of products leaving the selected i component as shown in Figure 10.

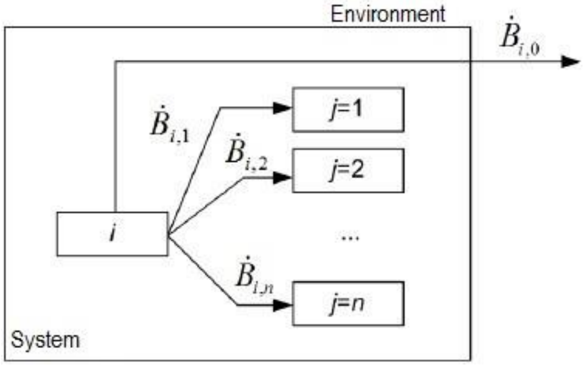


Figure 10 The method of separating the products of the i-th component of the extracted system [15]

Again, the total value of the product derived from the i-th component is calculated as the sum of the partial products leaving the i-th component as shown in the formula (20).

$$P_i = B_{i,0} + \sum_{j=1}^{n} B_{i,j} \tag{20}$$

where:
P_i – total exergy of the product leaving the i-th component,
$B_{i,0}$ – exergy of the stream discharged into the environment,
$B_{i,j}$ – exergy of the stream discharged from the i-th component to the j-th component,
n – component number.

4.2. Exergy costs allocation

Determining the exergy costs of components characterised by multiple streams (leaving or entering components) is connected with the necessity of following several statements, which are described below:

The first theorem (P1) - the exergy cost of the Exergy B * stream, the F fuel or the P product is the amount of exergy needed to make it, so it is possible to formulate so many exergy cost balances from how many components the analysed system consists of [16].

The second theorem (P2) - the exergy cost of streams flowing from outside the system boundary to the analysed system equals their exergy [16].

Third theorem (P3) - all costs generated during the production process must be included in the cost of the final product. Losses accompanying the work of individual components are allocated a cost equal to zero [2].

Fourth theorem (P4) - if the stream leaving the extracted component is part of the fuel stream supplying this component, its exergy cost is identical to the cost of the stream flowing into this component. On the other hand, when the product of a given component consists of many streams, they are allocated the same exergy cost [16].

Accordingly, for the first theorem **(P1)**, can be written the following property (21):

$$\mathbf{A} \cdot \mathbf{B}^* = \mathbf{0} \tag{21}$$

where:
$\mathbf{A}$ – incidence matrix,
B^* – column vector of values of exergy costs for individual streams.

Referring to the above property, it is possible to formulate so many balance equations, how many components were separated in the analysed system. However, the number of equations is insufficient, hence to complete the matrix of the structure with additional equations, it is needed to use the other theorems.

The equation for the second theorem **(P2)** has the form (22):

$$\boldsymbol{\alpha}_\mathbf{e} \cdot \mathbf{B}^* = \boldsymbol{\omega}_\mathbf{e} \tag{22}$$

where:
α_e – matrix of inflow of exergy fuel flowing into the system from outside the system boundary,
ω_e – vector of the exergy value of fuel flowing into the system from outside the system boundary.

Referring to the fourth theorem **(P4)**, the equation describing it can be written in the form (23):

$$\boldsymbol{\alpha}_{\mathbf{x}} \cdot \mathbf{B}^{*} = \mathbf{0} \tag{23}$$

where:
α_x – matrix of cost allocation factors.

According to this statement, the so-called exergy costs allocation should be conducted while choosing the appropriate method. A distinction is therefore made between "rule F" or "rule P".

4.2.1. Rule F

Rule F - if the selected component is fed by the exergy flow described as "F" fuel, and, at least two streams leave it, with some of them being "P" products, and the others are defined as fuel due to being part of the fuel supplying this component, the individual exergy costs of fuel streams are equal. This is called "Rule F", which is presented in the diagram below [17].

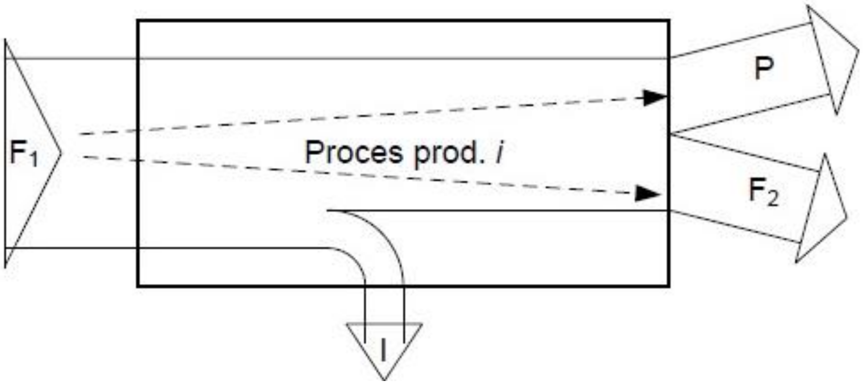


Figure 11 Diagram showing the "rule F" in the allocation of exergy costs [17]

For that application following relationship can be written (24) [17]:

$$\mathbf{k}^{*}_{\mathbf{F1}} = \mathbf{k}^{*}_{\mathbf{F2}} \tag{24}$$

where:
k^{*}_{F1}– the value of the specific exergy cost of fuel stream 1,
k^{*}_{F2} – the value of the specific exergy cost of fuel stream 2.

Hence, starting from equation (24), equation (25) is obtained [17]:

$$\frac{\mathbf{F}^{*}_{\mathbf{1}}}{\mathbf{F}_{\mathbf{1}}} = \frac{\mathbf{F}^{*}_{\mathbf{2}}}{\mathbf{F}_{\mathbf{2}}} \tag{25}$$

where:
F^{*}_{1} – the cumulative value of exergy needed to produce fuel 1,
F^{*}_{2} – the cumulative value of exergy needed to produce fuel 2,
F_1 – the value of exergy of fuel 1,
F_2 – the value of exergy of fuel 2.

Citing the equation (25) it can be concluded that the ratios of cumulative exergy flows to the exergy values of individual streams in relation to fuels 1 and 2 are equal.

Due to the fact that in the diagnosed system, exergy values of "F" fuel streams were determined, it became possible to determine the coefficients for the allocation of exergy costs. The mathematical form of the cost ratio is shown in the formula (26) [17]:

$$\mathbf{x} = \frac{\mathbf{F_2}}{\mathbf{F_1}} \tag{26}$$

where:
x – coefficient for exergy costs allocation of streams.

Hence, the final formula for the cumulative sum of fuel exergy equation including the cost allocation coefficient is (27):

$$-\mathbf{x_1 F_1^* + F_2^* = 0} \tag{27}$$

It results from the use of the formula (26) in equation (25).

4.2.2. Rule P

Rule P - if the selected component is supplied by the exergy flow described as fuel "F", and at least two streams which are defined as "P" products leave it, the specific exergy costs of the product streams are the same. This is called "Rule P", which is shown in the diagram below [17].

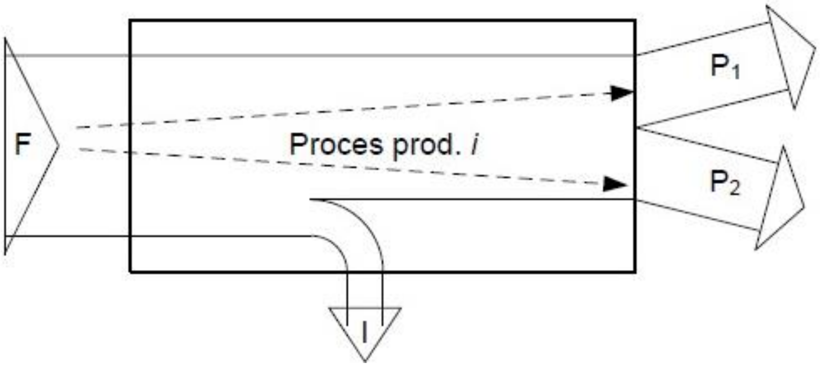


Figure 12 Diagram showing the "rule P" in the allocation of exergy costs [17].

For that application relationship (28) can be written [17]:

$$\mathbf{k_{P1}^* = k_{P2}^*} \tag{28}$$

where:
$\mathrm{k_{P1}^*}$– the value of the specific exergy cost of product stream 1,
$\mathrm{k_{P2}^*}$ – the value of the specific exergy cost of product stream 2.

Hence, starting from equation (28), equation (29) is obtained [17]:

$$\frac{\mathbf{P_1^*}}{\mathbf{P_1}} = \frac{\mathbf{P_2^*}}{\mathbf{P_2}} \tag{29}$$

where:
P_1^* – the cumulative value of exergy needed to produce product 1,
P_2^* – the cumulative value of exergy needed to produce product 2,
P_1 – the value of exergy of product 1,
P_2 – the value of exergy of product 2.

Relying on the equation (29), it can be concluded that the ratios of cumulative exergy flows to the exergy values of individual streams in relation to products 1 and 2 are equal.

Due to the fact that in the diagnosed system, the exergy values of the "P" product streams were determined, it became possible to determine the coefficients for the allocation of exergy costs. The mathematical form of the cost ratio is shown in the formula (30) [17]:

$$\mathbf{x} = \frac{\mathbf{P_2}}{\mathbf{P_1}} \tag{30}$$

where:
x – coefficient for exergy costs allocation of streams.

Hence, the final formula for the cumulative sum of products exergy equation including the cost allocation coefficient is (31):

$$-x_1 P_1^* + P_2^* = 0 \tag{31}$$

It results from the use of the formula (30) in equation (29).

5. Thermoeconomic analysis of a Combined Cycle Gas Turbine power plant

Two systems were modelled in the dissertation. In this chapter calculations will be explained for one of them. For the sake of clarity, a simpler cycle (CCGT) has been chosen to serve as an example.

5.1. Preliminary information on CCGT plant

Combined Cycle Gas Turbine are one of the most popular power and combined heat and power plants worldwide. This is mainly due to their high efficiency, availability and flexibility. They are simply a combination of open-cycle gas turbine with steam cycle which has heat recovery steam generator instead of a boiler.

Figure 13 presents a diagram of a simple CCGT plant modelled in the commercial software THERMOFLEX 26 [1] software. THERMOFLEX allows to create a mathematical model of the selected power unit. The structure of such a system consists in selecting and combining the appropriate components to obtain a complete system, as well as determining the initial thermodynamic parameters. Thanks to this, after the simulation, a ready set of parameters for all streams of the extracted block is obtained. As one can see in the figure above, the analysed power plant consists of 34 components and 43 streams. However, the method for exergy analysis requires more streams to be defined to have as many equations as unknown to get determined system of equations. They are showed in Appendix A which presents a diagram of a simple gas and steam power plant modelled in the THERMOFLEX 26 [1] software with marked additional streams.

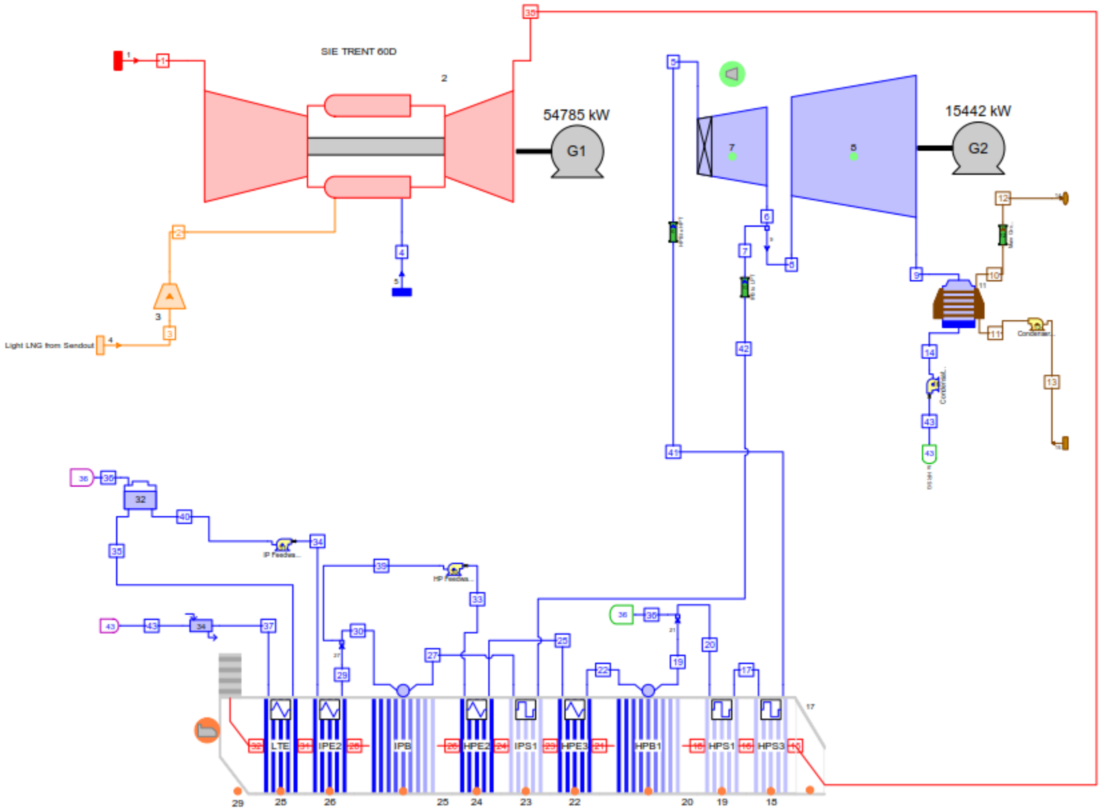


Figure 13 Combined Cycle Gas Turbine system presented in Thermoflex 26 [1]

After completing the drawing system can be described as consisting of 35 elements (equipment and sources) and 58 streams. Table 3 presents components included in the layout of the gas-steam power plant presented in Figure 13.

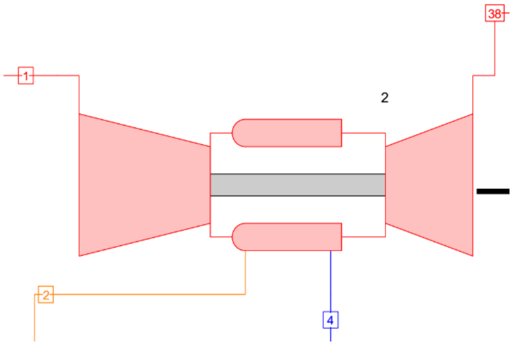
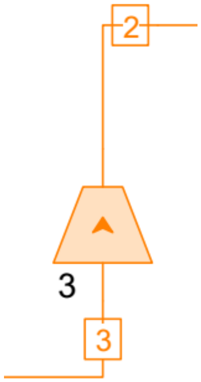
Table 3 List of components of the analyzed simple gas and steam system

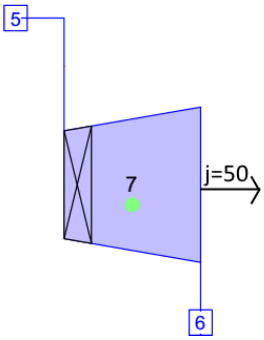
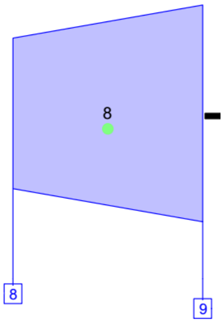
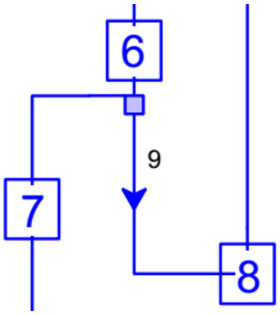
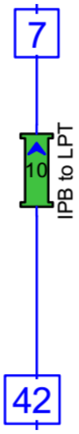
Component number j	**Description of the component**
1	Gas/Air Source
2	Gas Turbine
3	Fuel Compressor
4	Fuel Source
5	Water Source
6	Pipe
7	ST 1: Steam Turbine Group 1
8	ST 2: Steam Turbine Group 2
9	Mixer
10	Pipe
11	Water-cooled Condenser
12	Pipe
13	Pump
14	Brine Sink
15	Brine Source
16	Pump
17	HRSG 1: Duct - GT to Horizontal HRSG
18	HRSG 1: Superheater
19	HRSG 1: Superheater
20	HRSG 1: Evaporator
21	Splitter
22	HRSG 1: Economiser
23	HRSG 1: Superheater
24	HRSG 1: Economiser
25	HRSG 1: Evaporator
26	HRSG 1: Economiser
27	Splitter
28	HRSG 1: Economiser
29	HRSG 1: Steel Stack
30	Pump
31	Pump
32	Deaerator
34	Makeup / Blowdown
35	Generator 1
36	Generator 2

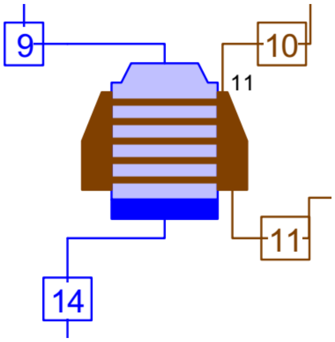
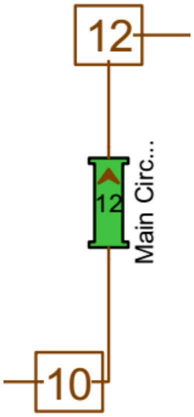
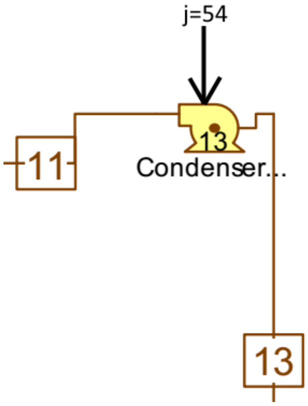
The discussed cycle is modelled consisting of the above components. Presenting the simplified operation of a given system: a stream of air and natural gas is supplied to the combustion chamber of the gas turbine generating a combustible mixture, which then causes combustion of elevated temperature flue gases at increased pressure. These fumes are then directed to the gas turbine, where as a result of their expansion, mechanical power is generated on the shaft, resulting in driving the compressor and the generator. In addition to electricity generated at the terminals of the generator, from the gas turbine set, exhaust fumes are fed to the boiler (Heat Recovery Steam Generator), whose task is to heat the feedwater, evaporate it and overheat the steam generated, which is then fed to a steam turbine. In turn, in this component, as a result of steam expansion, mechanical power is generated that drives the generator, as well as low-temperature and low-pressure steam supplying the condenser. Condensate leaving the condenser goes to the feedwater pump, thus increasing the pressure. Water with increased pressure goes to the recovery boiler, thus closing the cycle and the whole cycle is repeated from the beginning.

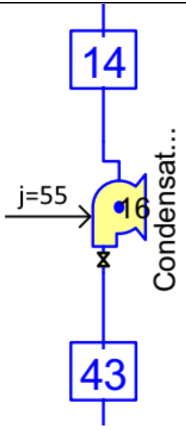
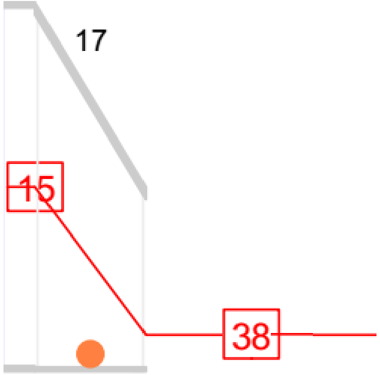
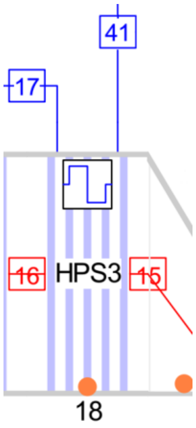
Table 4 shows a division of exergy flows into fuels and products for CCGT system components according to the method presented in chapter 4.

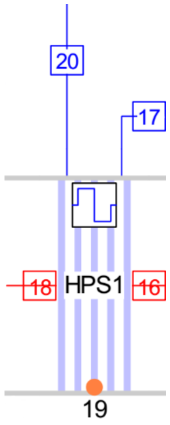
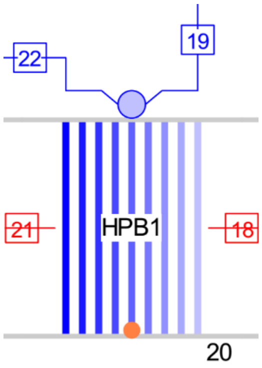
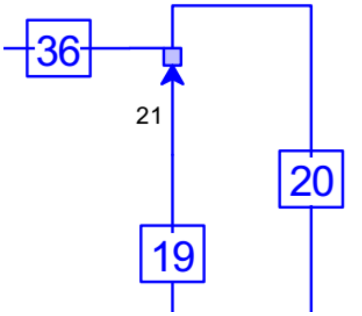
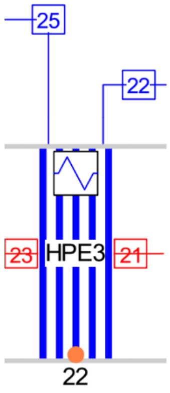
Table 4 The method of splitting exergy flows into fuels and products for exemplary components of a system

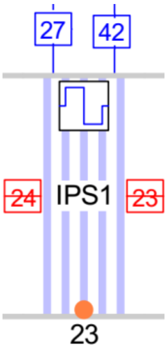
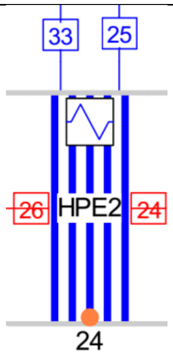
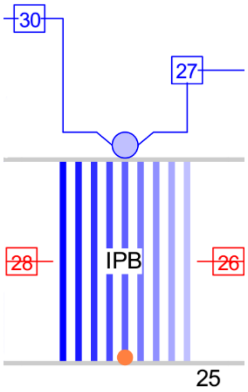
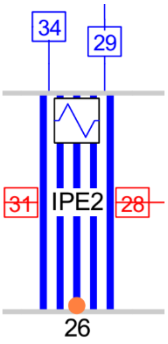
Component	Representation	Fuel	Product
Gas Turbine		$B_1 + B_2 + B_4$	$B_{38} + B_{45}$
Fuel Compressor		B_{48}	$B_2 - B_3$

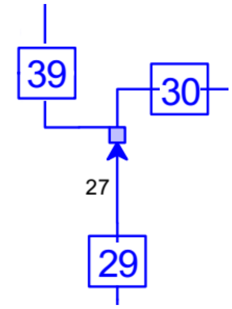
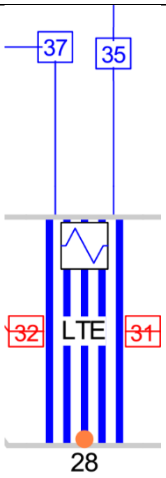
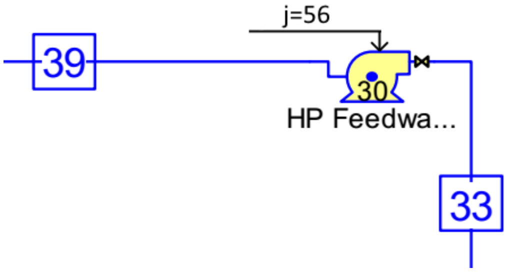
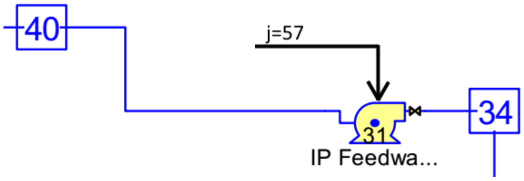
Component	Representation	Fuel	Product
ST 1: ST Group		$B_5 - B_6$	B_{50}
ST 2: ST Group		$B_8 - B_9$	B_{51}
Mixer		$B_6 + B_7$	B_8
Pipe		B_{42}	B_7

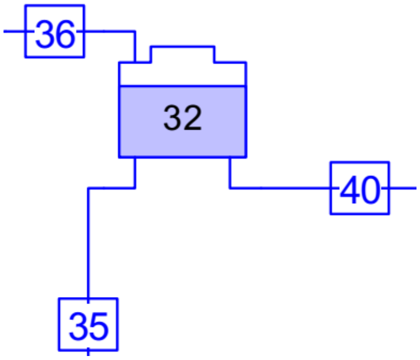
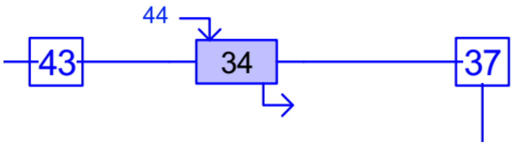
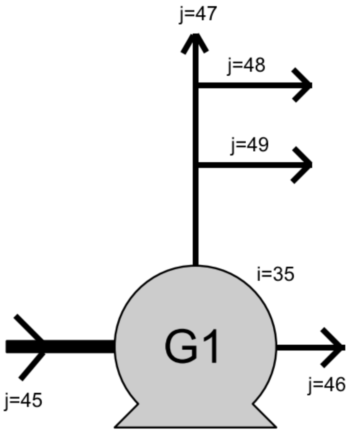
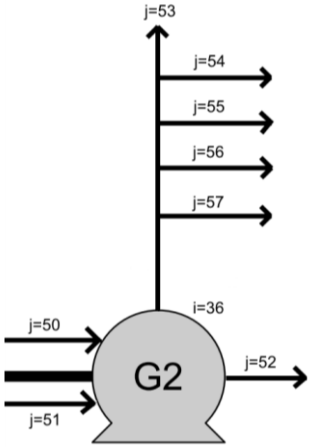
Component	Representation	Fuel	Product
Water-cooled Condenser		B_1	$B_2 + B_3$
Pipe		$B_9 - B_{14}$	$B_{10} - B_{11}$
Pump		B_{54}	$B_{11} - B_{13}$

Component	Representation	Fuel	Product
Pump		B_{55}	$B_{43} - B_{14}$
HRSG 1: Duct - GT to Horizontal HRSG		B_{38}	B_{15}
HRSG 1: Superheater		$B_{15} - B_{16}$	$B_{41} - B_{17}$

Component	Representation	Fuel	Product
HRSG 1: Superheater		$B_{16} - B_{18}$	$B_{17} - B_{20}$
HRSG 1: Evaporator		$B_{18} - B_{21}$	$B_{19} - B_{22}$
Splitter		B_{19}	$B_{20} + B_{36}$
HRSG 1: Economiser		$B_{21} - B_{23}$	$B_{22} - B_{25}$

Component	**Representation**	**Fuel**	**Product**
HRSG 1: Superheater		$B_{23} - B_{24}$	$B_{42} - B_{27}$
HRSG 1: Economiser		$B_{24} - B_{26}$	$B_{25} - B_{33}$
HRSG 1: Evaporator		$B_{26} - B_{28}$	$B_{27} - B_{30}$
HRSG 1: Economiser		$B_{28} - B_{31}$	$B_{29} - B_{34}$

Component	**Representation**	**Fuel**	**Product**
Splitter		B_{29}	$B_{30} + B_{39}$
HRSG 1: Economiser		$B_{31} - B_{32}$	$B_{35} - B_{37}$
Pump		B_{56}	$B_{33} - B_{39}$
Pump		B_{57}	$B_{34} - B_{40}$

Component	Representation	Fuel	Product
Deaerator		$B_{35} + B_{36}$	B_{40}
Makeup / Blowdown		$B_{44} + B_{43}$	B_{37}
Generator 1		B_{45}	$B_{47} + B_{48} + B_{49}$
Generator 2		$B_{50} + B_{51}$	$B_{53} + B_{54} + B_{55}$ $+ B_{56} + B_{57}$

5.2. Simulations and exergy flows calculations of the CCGT plant

Simulations of the power plant which is the subject of the study were made for two different sets of operational parameters which are presented in Table 5. First set of parameters, named reference state is a state where the plant should work as effectively as possible. Second state – operational consists of parameters set in such a way to reflect deterioration of the equipment. Thus, system working with parameters of operational state is foreseen to work less effectively. Thermoeconomic analysis is based on a comparison of the reference state of the given system with any other operational states.

Table 5 List of parameters set up differently within the operational states of the analyzed system

Parameter	**Value**	
	Reference state x_0	**Operational state x_1**
Condenser pressure [bar]	0.040	0.044
1st stage steam turbine isentropic efficiency [%]	87.69	80.77
2nd stage steam turbine isentropic efficiency [%]	88.97	81.93
Min **Δ**T HRSG [K]	5	7
Pump [1] isentropic efficiency [%]	85.65	80

Referring to Table 5 two operating conditions were analysed, which differed among themselves: condenser pressure, internal efficiency of the steam turbine, isentropic efficiency of the water feed pump and minimum temperature difference in heat recover steam generator. The purpose of the diagnosis was to check how the deterioration of these parameters in relation to the operational state influenced the operation of the discussed CCGT system.

Table 6 Table with thermodynamic parameters for individual flow streams for reference state

Stream	**j**	**p [bar]**	**T [°C]**	**m [kg/s]**	**h [kJ/kg]**	**s [kJ/kgK]**	**b_f [kJ/kg]**
Air	1	1.01	20.0	154.4	20.12	0.00	19.87
Fuel	2	55.32	371.9	2.7	1824.43	6.64	1247.23
Fuel	3	1.03	2.0	2.7	832.36	6.41	316.39
Water	4	55.32	20.0	3.5	89.19	0.30	8.51
Steam	5	29.00	399.0	13.3	3231.10	6.94	1336.13
Steam	6	3.10	152.2	13.0	2765.13	7.07	832.90
Steam	7	3.10	164.2	4.9	2790.80	7.13	842.41
Steam	8	3.10	155.5	17.9	2772.24	7.09	835.46
Steam	9	0.04	29.0	18.2	2235.04	7.43	206.30
Sea Water	10	1.61	25.0	1934.3	95.56	0.33	9.17
Sea Water	11	2.23	20.0	1934.3	76.48	0.26	7.33
Sea Water	12	1.01	25.0	1934.3	95.55	0.33	8.66
Sea Water	13	1.01	20.0	1934.3	76.34	0.26	7.21
Water	14	0.40	29.0	18.2	121.50	0.42	6.14
Flue Gas	15	1.03	420.4	159.9	895.80	7.73	372.37
Flue Gas	16	1.03	406.2	159.9	879.54	7.71	362.50
Steam	17	30.41	318.2	13.28	3038.62	6.61	1232.52
Flue Gas	18	1.03	388.9	159.9	859.82	7.68	350.73

Stream	j	p [bar]	T [°C]	m [kg/s]	h [kJ/kg]	s [kJ/kgK]	b_f [kJ/kg]
Steam	19	30.99	235.7	13.604	2803.32	6.17	1117.13
Steam	20	30.99	235.7	13.28	2803.32	6.17	1117.13
Flue Gas	21	1.02	250.7	159.9	705.14	7.42	266.96
Water/Steam	22	30.99	231.6	13.67	997.75	2.63	280.76
Flue Gas	23	1.02	239	159.9	692.27	7.39	260.80
Flue Gas	24	1.02	237.3	159.9	690.40	7.39	259.93
Water/Steam	25	31.31	199.2	13.67	849.32	2.32	215.50
Flue Gas	26	1.02	215.3	159.9	666.30	7.34	248.85
Steam	27	3.43	138.2	4.94	2731.11	6.95	833.66
Flue Gas	28	1.02	153.2	159.9	598.82	7.20	221.48
Water	29	3.43	134.2	18.64	564.35	1.68	105.74
Water	30	3.43	134.2	4.965	564.35	1.68	105.74
Flue Gas	31	1.01	137.9	159.9	582.31	7.16	215.59
Flue Gas	32	1.01	110	159.9	552.30	7.08	206.15
Water	33	31.92	135	13.67	569.66	1.68	109.68
Water	34	3.54	101.2	18.64	424.42	1.32	63.78
Water	35	1.05	91.11	18.31	381.74	1.21	52.42
Steam	36	30.99	235.7	0.3233	2803.32	6.17	1117.13
Water	37	1.09	29.03	18.31	121.78	0.42	6.20
Flue Gas	38	1.04	422.4	159.9	898.09	7.73	374.15
Water	39	3.43	134.2	13.67	564.35	1.68	105.74
Water	40	1.05	101.1	18.64	423.81	1.32	63.42
Steam	41	29.94	400.8	13.28	3233.61	6.93	1341.69
Steam	42	3.30	166	4.94	2793.23	7.11	851.06
Water	43	1.09	29.08	18.22	121.98	0.42	6.23
Make-up water	44	1.09	20	0.094	84.01	0.30	3.01

Table 7 Work, heat and energy streams for reference state

Stream j	45	46	47	48	49	50	51
E [kW]	55638.0	853.3	50807.0	3846.0	132.0	6018.0	9864.0
Stream j	52	53	54	55	56	57	
E [kW]	439.6	15050.2	292.3	9.8	77.2	12.5	

Table 6 and Table 7 present data on thermodynamic parameters of streams constituting the analysed cycle for its reference state. Values of pressure, temperature as well as mass and energy balances were obtained by conducting simulations in the Thermoflex 26 [1] program, after which the results were implemented in the Excel program with CoolProp [2] and Refprop [3] add-ins, which were used to calculate the value of specific enthalpy, entropy and exergy. The specified exergy flows were calculated on the basis of the equations contained in chapter 3.

Table 8 Table with thermodynamic parameters for individual flow streams for operational state

Stream	j	p [bar]	T [°C]	m [kg/s]	h [kJ/kg]	s [kJ/kgK]	b_f [kJ/kg]
Air	1	1.01	20.0	156.5	20.12	0.00	19.87
Fuel	2	55.32	376.1	2.8	1838.78	6.66	1255.52
Fuel	3	1.03	2.0	2.8	832.36	6.41	316.39
Water	4	55.32	20.0	3.7	89.19	0.30	8.51
Steam	5	29.00	399.0	13.6	3231.10	6.94	1336.13
Steam	6	3.10	166.5	13.3	2795.67	7.14	844.23
Steam	7	3.10	164.2	5.0	2790.80	7.13	842.41
Steam	8	3.10	165.8	18.2	2794.19	7.14	843.56
Steam	9	0.04	30.6	18.6	2298.05	7.59	225.51
Sea Water	10	1.61	25.0	2021.9	95.56	0.33	9.16
Sea Water	11	2.23	20.0	2021.9	76.48	0.26	7.32
Sea Water	12	1.01	25.0	2021.9	95.55	0.33	9.10
Sea Water	13	1.01	20.0	2021.9	76.34	0.26	7.21
Water	14	0.40	30.6	18.6	128.40	0.45	6.81
Flue Gas	15	1.03	421.6	162.2	901.13	7.73	374.33
Flue Gas	16	1.03	407.3	162.2	882.05	7.71	365.20
Steam	17	30.41	318.2	13.6	3038.62	6.61	1232.52
Flue Gas	18	1.03	389.9	162.2	863.56	7.68	354.16
Steam	19	30.99	235.7	13.9	2803.32	6.17	1117.13
Steam	20	30.99	235.7	13.6	2803.32	6.17	1117.13
Flue Gas	21	1.02	250.7	162.2	705.14	7.42	266.96
Water/Steam	22	30.99	231.6	14.0	997.75	2.63	280.76
Flue Gas	23	1.02	238.9	162.2	694.62	7.39	260.97
Flue Gas	24	1.02	237.2	162.2	692.75	7.39	260.10
Water/Steam	25	31.31	199.2	14.0	849.32	2.32	215.50
Flue Gas	26	1.02	215.0	162.2	668.41	7.34	248.92
Steam	27	3.43	138.2	5.0	2731.11	6.95	833.66
Flue Gas	28	1.02	153.2	162.2	601.20	7.20	221.68
Water	29	3.43	134.2	19.0	564.35	1.68	105.74
Water	30	3.43	134.2	5.0	564.35	1.68	105.74
Flue Gas	31	1.01	137.9	162.2	584.68	7.16	215.77
Flue Gas	32	1.01	110.6	162.2	555.29	7.08	206.51
Water	33	31.92	135.0	14.0	569.66	1.68	109.68
Water	34	3.54	101.2	19.0	424.42	1.32	63.78
Water	35	1.05	91.1	18.7	381.74	1.21	52.42
Steam	36	30.99	235.7	0.3	2803.32	6.17	1117.13
Water	37	1.09	30.7	18.7	128.67	0.45	6.88
Flue Gas	38	1.04	423.6	162.2	902.11	7.73	375.31
Water	39	3.43	134.2	14.0	564.35	1.68	105.74
Water	40	1.05	101.1	19.0	423.81	1.32	63.42
Steam	41	29.94	400.8	13.6	3233.61	6.93	1341.69

Stream	j	p [bar]	T [°C]	m [kg/s]	h [kJ/kg]	s [kJ/kgK]	b_f [kJ/kg]
Steam	42	3.30	166.0	5.0	2793.23	7.11	851.06
Water	43	1.09	30.7	18.6	128.88	0.45	6.91
Make-up water	44	1.09	20.0	0.1	84.01	0.30	3.02

Table 9 Work, heat and energy streams for operational state

Stream j	45	46	47	48	49	50	51
E [kW]	57078.0	870.9	51987.0	4088.0	132.0	5753.0	9339.0
Stream j	52	53	54	55	56	57	
E [kW]	423.2	14240.8	326.7	10.0	78.8	12.7	

Table 8 and Table 9 presents data on thermodynamic parameters of streams constituting the analysed cycle for its operational state. The parameters were calculated in the same manner as described for Table 6 and Table 7.

In turn conditions presents the values of exergy flows for both operational states. Exergy flows were obtained by multiplying mass flow and specific physical exergy for all streams but fuel. For fuel streams j= {2,3}, in addition to physical exergy, chemical exergy was added. Specific chemical exergy was calculated according to formula (10) and multiplied by mass flow. X_0 represents reference state while X_1 stands for operational state.

Table 10 Exergy values for reference and operational conditions

j	Stream	Exergy [kW] Reference state X_0	Exergy [kW] Operational state X_1
1	Air	3067.54	3109.26
2	Fuel	142796.75	145993.28
3	Fuel	140241.59	143358.07
4	Water	29.84	31.21
5	Steam	17743.79	18144.63
6	Steam	10786.04	11186.03
7	Steam	4161.52	4208.69
8	Steam	14946.44	15386.48
9	Steam	3758.79	4187.71
10	Sea Water	17738.02	18524.04
11	Sea Water	14181.37	14806.03
12	Sea Water	16755.38	18403.10
13	Sea Water	13950.60	14582.39
14	Water	111.82	126.52
15	Flue Gas	59541.49	60715.54
16	Flue Gas	57964.18	59235.57
17	Steam	16367.80	16737.55
18	Flue Gas	56082.05	57444.35
19	Steam	15197.41	15539.26

j	Stream	Exergy [kW] Reference state X_0	Exergy [kW] Operational state X_1
20	Steam	14835.46	15170.60
21	Flue Gas	42686.55	43300.56
22	Water/Steam	3838.00	3925.04
23	Flue Gas	41701.19	42329.12
24	Flue Gas	41562.12	42187.97
25	Water/Steam	2945.82	3012.62
26	Flue Gas	39790.67	40374.37
27	Steam	4118.26	4164.94
28	Flue Gas	35415.22	35955.75
29	Water	1971.07	2009.14
30	Water	525.02	530.94
31	Flue Gas	34472.18	34998.37
32	Flue Gas	32963.05	33496.36
33	Water	1499.36	1533.37
34	Water	1188.86	1211.82
35	Water	959.83	978.70
36	Steam	361.17	368.21
37	Water	113.53	128.38
38	Flue Gas	59826.53	60875.21
39	Water	1445.52	1478.30
40	Water	1182.17	1205.00
41	Steam	17817.59	18220.10
42	Steam	4204.22	4251.88
43	Water	113.48	128.24
44	Make-up water	0.28	0.29
45	GT shaft power	55638.00	57078.00
46	Heat from G1	0.00	1.00
47	Net electricity from G1	50807.00	51987.00
48	Electricity to fuel compressor	3846.00	4088.00
49	Aux of gas turbine	132.00	132.00
50	Shaft power of ST group 1	6018.00	5753.00
51	Shaft power of ST group 2	9864.00	9339.00
52	Heat from G2	0.00	1.00
53	Net electricity from G2	15050.15	14240.84
54	Power to Pump 13	292.30	326.70
55	Power to Pump 16	9.84	9.96
56	Power to Pump 30	77.23	78.84
57	Power to Pump 31	12.48	12.66

The division of two operational states required the assumption of an equal output net power in each of them, therefore it was assumed that the obtained net power crossing system boundary of the CCGT cycle should be equal to 65 857 kW in both working states.

Referring to Table 10, it can be seen at the outset that the operation of the system under analysis as a result of the introduced changes has deteriorated. As can be seen with the determined net output power from the system, a larger fuel stream should be delivered to the system in the operational state in relation to the reference one, which translates to a greater value of the exergy flow. In addition, considering the condenser, it can be seen that a larger stream of heat exergy goes to the environment (sea water) in the operational state compared to the reference one, so the external loss due to dissipation is greater in the operational state. At the same time, it should be noted that the feed water pump as a result of changes such as the reduction of the isentropic efficiency of this pump, in the operational state increased its demand for electricity. Electricity consumption of other pumps rises just a bit which is a result of flow increase.

5.3. Algorithm of exergy cost calculation

As mentioned this dissertation will be based on the so-called matrix method, which allows to conduct diagnosis also for very complex systems. When starting such an analysis it is necessary to define for a particular block which of the exergy flows are fuels marked with the letter "F" and which are the "P" products for each of the components.

The way how fuels and products for particular components of a simple CCGT plant are described is presented in Table 4.

Performing exergy analysis using the matrix method requires the construction of appropriate matrices, i.e. incidence matrix **A**, the fuel matrix $\mathbf{A_F}$ and the matrix of products $\mathbf{A_P}$. These matrices allow in the further part for the quick and accurate determination of fuels, products and irreversibility for each of the presented components, so that with complex systems it is not required to perform separate calculations for each of the devices. Individual lines are numbered because of the distinguished components, so in the case of CCGT plant analysed there are 29 lines available due to 29 components that work in the analysed system. Columns, however, are numbered taking into account the number of streams of a given circulation, which in this case gives 57 streams. Therefore, the number of rows must be equal to the number of components, and the number of columns must correspond to the number of streams in the system.

Matrices **A**, $\mathbf{A_F}$ and $\mathbf{A_P}$ are related to each other by the relationship shown in (32):

$$\mathbf{A} = \mathbf{A_F} - \mathbf{A_P} \tag{32}$$

where:
$\mathbf{A}$ – incidence matrix,
$\mathbf{A_F}$ – fuels matrix,
$\mathbf{A_P}$ – products matrix.

In the form of a matrix product, one can also write universally binding mass and energy conservation laws as well as Gouy-Stodola law describing exergy losses occurring in the case of irreversible processes. The way of constructing certain balances in matrix form is shown below.

The individual matrices (incidence matrix $\mathbf{A}$, fuels matrix $\mathbf{A_F}$ and products matrix $\mathbf{A_P}$) for the analysed CCGT power plant are showed in appendices A1, A2 and A3.

Incidence matrix $\mathbf{A}$ determines which of the individual streams feed or leave the selected system component. For such constructed matrix, the stream "j" taking the value "1" informs that it supplies the given component "i". The value "-1" indicates that the given stream "j" leaves the component "i", while the value "0" indicates the lack of flow with the given component "i".

In case of matrix $\mathbf{A_F}$ (as shown in Appendix A2) the "1" value of stream "j" indicates that it supplies the selected component. The value "-1" indicates that the given component’s "i" stream "j" is also part of the fuel that supplies this component. The "0" value, however, says no flow "j" to or from the "i" component.

The mass balance is given by formula (33) [16]:

$$\mathbf{A} \cdot \mathbf{M} = \mathbf{0} \tag{33}$$

where:
$\mathbf{A}$ – incidence matrix,
M – column vector of substance streams values.

In turn, the energy balance is as in formula (34) [16]:

$$\mathbf{A} \cdot \mathbf{E} = \mathbf{0} \tag{34}$$

where:
$\mathbf{A}$ – incidence matrix,
E – column vector of energy streams values.

However, the **exergy balance** can be written as in the formula (35) [16]:

$$\mathbf{A} \cdot \mathbf{Y_B} = \mathbf{I_B} \tag{35}$$

where:
$\mathbf{A}$ – incidence matrix,
$\mathrm{Y_B}$ – column vector of exergy flows values,
$\mathrm{I_B}$ – column vector of irreversibility values.

The irreversibility $\mathrm{I_B}$ value is the sum of internal and external losses of exergy, while internal losses are related to the imperfection of a given thermodynamic transformation, external are related to products with a positive exergy value, which are directed to the environment (they cross the boundary of the entire system). This relation is presented in (36).

$$\mathbf{I_B} = \mathbf{D_B} + \mathbf{L_B} \tag{36}$$

where:
$\mathrm{I_B}$ – column vector of irreversibility values,
$\mathrm{D_B}$ – column vector of internal irreversibility values,
$\mathrm{L_B}$ – column vector of external irreversibility values.

In addition, using matrices: $\mathbf{A_F}$ fuels and $\mathbf{A_P}$ products, it is possible to determine column vectors of the values of exergy flows of fuels and products for individual components [16] what is presented in equations (37) and (38).

$$\mathbf{A_F} \cdot \mathbf{Y_B} = \mathbf{F_B} \tag{37}$$

$$\mathbf{A_P} \cdot \mathbf{Y_B} = \mathbf{P_B} \tag{38}$$

where:
$\mathbf{A_F}$ – fuels matrix,
$\mathbf{A_P}$ – products matrix,
$\mathrm{Y_B}$ – column vector of exergy flows values,
$\mathrm{F_B}$ – column vector of exergy flows of fuels,
$\mathrm{P_B}$ – column vector of exergy flows of products.

When filling the product matrix (as shown in Appendix A3) with certain logical values, one should remember that the value "1" indicates that the given stream "j" leaves the component "i". The value "-1" refers to the stream "j" which flows into the given component "i" but forms part of the product of this component. In turn, the value "0" of the stream "j" shows no flow with the given component "i".

Using the above matrices, as well as relationships (35), (36), (37), (38), it is possible to determine the column vectors of F_B fuels, P_B products as well as I_B irreversibility for the analysed CCGT cycle. The following Table 11 summarize the received exergy values for both the reference state x_0 and the operational state x_1.

Table 11 Values of vectors for exergy flows of fuels, products and irreversibility of the CCGT power plant for the reference state x_0 and operation state x_1

		$x=x_0$	$x=x_0$	$x=x_0$	$x=x_1$	$x=x_1$	$x=x_1$
i	**Component**	**F_B**	**P_B**	**I_B**	**F_B**	**P_B**	**I_B**
2	**Gas Turbine**	146026.1	115464.5	30561.6	149265.7	117953.2	31312.5
3	**Fuel Compressor**	3846.0	2555.2	1290.8	4088.0	2635.2	1452.8
6	**Pipe**	17817.6	17743.8	73.8	18220.1	18144.6	75.5
7	**ST 1: ST Group**	6957.8	6018.0	939.8	6958.6	5753.0	1205.6
8	**ST 1: ST Group**	11187.7	9864.0	1323.7	11198.8	9339.0	1859.8
9	**Mixer**	14947.6	14946.4	1.1	15394.7	15386.5	8.2
10	**Pipe**	4204.2	4161.5	42.7	4251.9	4208.7	43.2
11	**Water-cooled Condenser**	3647.0	3556.7	90.3	4061.2	3718.0	343.2
12	**Pipe**	17738.0	16755.4	982.6	18524.0	18403.1	120.9
13	**Pump**	292.3	230.8	61.5	326.7	223.6	103.1
16	**Pump**	9.8	1.7	8.2	10.0	1.7	8.2
17	**HRSG 1: Duct - GT to Horizontal HRSG**	59826.5	59541.5	285.0	60875.2	60715.5	159.7
18	**HRSG 1: Superheater**	1577.3	1449.8	127.5	1480.0	1482.5	-2.6
19	**HRSG 1: Superheater**	1882.1	1532.3	349.8	1791.2	1566.9	224.3
20	**HRSG 1: Evaporator**	13395.5	11359.4	2036.1	14143.8	11614.2	2529.6
21	**Splitter**	15197.4	15196.6	0.8	15539.3	15538.8	0.4
22	**HRSG 1: Economiser**	985.4	892.2	93.2	971.4	912.4	59.0
23	**HRSG 1: Superheater**	139.1	86.0	53.1	141.2	86.9	54.2
24	**HRSG 1: Economiser**	1771.4	1446.5	325.0	1813.6	1479.3	334.3
25	**HRSG 1: Evaporator**	4375.5	3593.2	782.2	4418.6	3634.0	784.6
26	**HRSG 1: Economiser**	943.0	782.2	160.8	957.4	797.3	160.1
27	**Splitter**	1971.1	1970.5	0.5	2009.1	2009.2	-0.1
28	**HRSG 1: Economiser**	1509.1	846.3	662.8	1502.0	850.3	651.7
30	**Pump**	77.2	53.8	23.4	78.8	55.1	23.8

i	Component	F_B	P_B	I_B	F_B	P_B	I_B
31	**Pump**	12.5	6.7	5.8	12.7	6.8	5.8
32	**Deaerator**	1321.0	1182.2	138.8	1346.9	1205.0	141.9
34	**Makeup / Blowdown**	113.8	113.5	0.2	128.5	128.4	0.1
35	**Generator 1**	55638.0	54785.0	853.0	57078.0	56207.0	871.0
36	**Generator 2**	15882.0	15442.0	440.0	15092.0	14669.0	423.0

Analysing the results presented in Table 11 it can be concluded that the biggest losses so the greatest irreversibility of the thermodynamic process, appear at second component – gas turbine cycle. It results from the fact that combustion occurs in it as a very irreversible process. In addition, the full set of elements constituting to gas turbine in the analysis are treated as one component - it is not distributed between the compressor, combustion chamber and turbine, hence the obtained irreversibility is the sum of the imperfections of each of these devices.

On the basis of the results obtained in Table 11, it is possible to determine exergy efficiency and specific exergy consumption values based on equations (11), (12) as shown in Table 12.

Table 12 Values of exergy efficiency and specific consumption of exergy for individual components in the for the reference state x_0 and operation state x_1

i	Component	ηB $x=x_0$	kB $x=x_0$	ηB $x=x_1$	kB $x=x_1$
2	**Gas Turbine**	0.79	1.26	0.79	1.27
3	**Fuel Compressor**	0.66	1.51	0.64	1.55
6	**Pipe**	1.00	1.00	1.00	1.00
7	**ST 1: ST Group**	0.86	1.16	0.83	1.21
8	**ST 1: ST Group**	0.88	1.13	0.83	1.20
9	**Mixer**	1.00	1.00	1.00	1.00
10	**Pipe**	0.99	1.01	0.99	1.01
11	**Water-cooled Condenser**	0.98	1.03	0.92	1.09
12	**Pipe**	0.94	1.06	0.99	1.01
13	**Pump**	0.79	1.27	0.68	1.46
16	**Pump**	0.17	5.92	0.17	5.81
17	**HRSG 1: Duct - GT to Horizontal HRSG**	1.00	1.00	1.00	1.00
18	**HRSG 1: Superheater**	0.92	1.09	1.00	1.00
19	**HRSG 1: Superheater**	0.81	1.23	0.87	1.14
20	**HRSG 1: Evaporator**	0.85	1.18	0.82	1.22

i	Component	ηB $x=x_0$	kB $x=x_0$	ηB $x=x_1$	kB $x=x_1$
21	**Splitter**	1.00	1.00	1.00	1.00
22	**HRSG 1: Economiser**	0.91	1.10	0.94	1.06
23	**HRSG 1: Superheater**	0.62	1.62	0.62	1.62
24	**HRSG 1: Economiser**	0.82	1.22	0.82	1.23
25	**HRSG 1: Evaporator**	0.82	1.22	0.82	1.22
26	**HRSG 1: Economiser**	0.83	1.21	0.83	1.20
27	**Splitter**	1.00	1.00	1.00	1.00
28	**HRSG 1: Economiser**	0.56	1.78	0.57	1.77
30	**Pump**	0.70	1.43	0.70	1.43
31	**Pump**	0.54	1.87	0.54	1.86
32	**Deaerator**	0.89	1.12	0.89	1.12
34	**Makeup / Blowdown**	1.00	1.00	1.00	1.00
35	**Generator 1**	0.98	1.02	0.98	1.02
36	**Generator 2**	0.97	1.03	0.97	1.03

Analysing the above Table 12 and Table 11, it can be noticed that the smallest exergy efficiency, and hence the largest specific consumption of exergy, has the component number 16 – condensate pump. However absolute exergy loss of that pump is not that significant comparing to components like gas turbine, fuel compressor or steam turbine. The reason for small exergy efficiency of condensate pump is its low adiabatic efficiency equal to 14.57%. Other components characterised by large specific exergy consumption are gas turbine, fuel compressor, sea water pump and some exchangers and evaporators of HRSG. The smaller the degree of irreversibility of a given thermodynamic process, the higher the exergy efficiency of a given component and the smaller its specific exergy cost.

5.4. Exergy costs analysis of the CCGT Plant

Due to the fact that the matrix of the structure of the discussed system is not a square matrix, because there are 57 columns and 29 rows available which results from the number of components and streams, it is necessary to supplement this matrix by an additional 28 equations. For this reason, theories described in chapter 4.2 should be utilized, because they can also be interpreted in matrix form, which allows to construct a square matrix by adding necessary equations, and then to determine the cumulative exergy values of each stream.

The calculation of exergy costs in the matrix method involves, as mentioned in chapters 4.2 and 5.3, filling of the incidence matrix A with additional positions in order to obtain an A_k square matrix which allows to determine the exergy costs of individual streams. For this purpose, one should use discussed rules and equations. For the analysed system 28 additional equations are needed. Five of them results from the second theorem (P2), because the system is supplied from the outside of the system boundary with gas fuel, air, water for gas turbine combustor, make-up water and sea water, cost of which is to be equal to unity Therefore, referring to the second theorem (P2), one can write dependencies for components:

- gas turbine set,
- fuel compressor,
- water make-up,
- sea water pump.

For the gas turbine set, referring to the second theorem (P2), one can write two dependencies (39), (40):

$$B_1^* = B_1 \tag{39}$$

$$B_4^* = B_4 \tag{40}$$

where:
B_i^* - cumulative value of exergy needed to produce a given amount of stream i exergy,
B_i - value of exergy of fuel supplied from outside the system boundary.

For the rest of components listed above, referring to the second theorem (P2), one can write one dependence for each of them what is presented in equations (41), (42), (43):

$$B_3^* = B_3 \tag{41}$$

$$B_{13}^* = B_{13} \tag{42}$$

$$B_{44}^* = B_{44} \tag{43}$$

where:
B_i^* - cumulative value of exergy needed to produce a given amount of stream i exergy,
B_i - value of exergy of fuel supplied from outside the system boundary.

The remaining equations had to be supplemented based on the fourth (P4) theorem, hence on the basis of exergy costs allocation.

The method of determining the cost allocation ratios for selected components is described below.

Component 2 – gas turbine

An additional equation for this device results from the "P rule", because there are two products available: shaft power feeding the generator and high temperature fumes feeding the recovery boiler, where none of the products is a fragment of the fuel supplying this component. Thus, for this case, one can write equations (44), (45), (46) and (47):

$$k_{45}^* = k_{38}^* \tag{44}$$

$$\frac{B_{45}^*}{B_{45}} = \frac{B_{38}^*}{B_{38}} \tag{45}$$

$$x_1 = \frac{B_{45}^*}{B_{38}^*} = \frac{B_{45}}{B_{38}} \tag{46}$$

$$B_{45} - x_1 \cdot B_{38} = 0 \tag{47}$$

where:
k_{45}^* – the value of the exergy cost of shaft power produced in the gas turbine,
k_{38}^* – the value of exergy cost of the exhaust gases stream coming from the gas turbine,

B_{45} – the value of the exergy of shaft power generated by the gas turbine,
B_{38} – the value of exergy of exhaust gases stream feeding the recovery boiler,
B^*_{45} – the cumulative value of exergy needed to produce a certain amount of shaft power,
B^*_{38} – the cumulative value of the exergy necessary to produce a certain amount of exergy of the exhaust gases stream derived from the gas turbine,
x_1 – exergy cost allocation coefficient for component 2.

Component 18 – Superheater

An additional equation for this component results from the "rule F" because the exhaust gases leaving the recovery boiler's superheater are part of the fuel that supplies this component. Due to this, one can write equations (48), (49), (50) and (51):

$$k^*_{15} = k^*_{16} \tag{48}$$

$$\frac{B^*_{15}}{B_{15}} = \frac{B^*_{16}}{B_{16}} \tag{49}$$

$$x_1 = \frac{B^*_{15}}{B^*_{16}} = \frac{B_{15}}{B_{16}} \tag{50}$$

$$B_{15} - x_2 \cdot B_{16} = 0 \tag{51}$$

where:
k^*_{16} – the value of the exergy cost of exhaust gases stream leaving the superheater,
k^*_{15} – the value of the exergy cost of exhaust gases stream feeding the superheater,
B_{16} – the value of the exergy of exhaust gases stream leaving the superheater,
B_{15} – the value of exergy of exhaust gases stream feeding the superheater,
B^*_{16} – the cumulative value of exergy needed to produce a certain amount of exergy of exhaust gases stream leaving the superheater,
B^*_{15} – the cumulative value of the exergy necessary to produce a certain amount of exergy of the exhaust gases stream feeding the superheater,
x_2 – exergy cost allocation coefficient for component 18.

The same rule and thus way of calculation applies to the rest of recovery boiler heat exchangers – components number: 19, 20, 22, 23, 24, 25, 26, 28. Applying the above method following exergy cost allocation coefficients are obtained: $x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}$.

Component 27 – Splitter

An additional equation for this device results from the "P rule", because there are two products available: water stream number 30 and water stream number 39, where none of the products is a fragment of the fuel supplying this component. Thus, for this case, one can write equations (52), (53), (54) and (55):

$$k^*_{30} = k^*_{39} \tag{52}$$

$$\frac{B^*_{30}}{B_{30}} = \frac{B^*_{39}}{B_{39}} \tag{53}$$

$$x_1 = \frac{B^*_{30}}{B^*_{39}} = \frac{B_{30}}{B_{39}} \tag{54}$$

$$B_{30} - x_1 \cdot B_{39} = 0 \tag{55}$$

where:
k_{30}^{*} – the value of the exergy cost of first water stream leaving the splitter,
k_{39}^{*} – the value of exergy cost of second water stream leaving the splitter,
B_{30} – the value of the exergy of first water stream leaving the splitter,
B_{39} – the value of exergy of second water stream leaving the splitter,
B_{30}^{*} – the cumulative value of exergy needed to produce a certain amount of exergy of first water stream leaving the splitter,
B_{39}^{*} – the cumulative value of the exergy necessary to produce a certain amount of exergy of second water stream leaving the splitter,
x_{11} – exergy cost allocation coefficient for component 27.

The same rule and thus way of calculation applies to an other splitter – component number 21. Applying the above method exergy cost allocation coefficients x_{12} is obtained.

Component 7 – Steam turbine

An additional equation for this component results from the "rule F" because the steam leaving the first group of steam turbine is a part of the fuel that supplies second group of this steam turbine. Due to this, one can write equations (56), (57), (58) and (59):

$$\mathrm{k}_5^{*} = \mathrm{k}_6^{*} \tag{56}$$

$$\frac{\mathrm{B}_5^{*}}{\mathrm{B}_5} = \frac{\mathrm{B}_6^{*}}{\mathrm{B}_6} \tag{57}$$

$$\mathrm{x}_1 = \frac{\mathrm{B}_5^{*}}{\mathrm{B}_6^{*}} = \frac{\mathrm{B}_5}{\mathrm{B}_6} \tag{58}$$

$$\mathrm{B}_5 - \mathrm{x}_2 \cdot \mathrm{B}_6 = 0 \tag{59}$$

where:
k_6^{*} – the value of the exergy cost of exhaust steam leaving the first steam turbine group,
k_5^{*} – the value of the exergy cost of steam feeding the first steam turbine group,
B_6 – the value of the exergy of exhaust steam leaving the first steam turbine group,
B_5 – the value of exergy of steam feeding the first steam turbine group,
B_6^{*} – the cumulative value of exergy needed to produce a certain amount of exergy of exhaust steam leaving the first steam turbine group,
B_5^{*} – the cumulative value of the exergy necessary to produce a certain amount of exergy of steam feeding the first steam turbine group,
x_{13} – exergy cost allocation coefficient for component 7.

The same rule and thus way of calculation applies to second group of steam turbine – component number 8 only with one difference – steam stream leaving the turbine fuels a condenser . Applying the above method exergy cost allocation coefficients x_{14} is obtained. The same rule is as well utilized for component number 11 – condenser. Following the above steps results in calculating coefficient x_{15}.

Component 35 – Generator 1

Additional equations for this device results from the "P rule", because there are four products available: heat created due to losses, electricity feeding fuel compressor, electricity feeding auxiliary loads of gas turbine and net electricity leaving the system boundary. Due to the fact 4 products are available it is possible to write three equations for the following pairs of exergy flows:

- B_{47} and B_{46},
- B_{47} and B_{48},
- B_{47} and B_{49}.

For each pair of streams, a separate exergy cost allocation coefficient should be calculated. For streams B_{47} and B_{46} procedure is as shown in equations (60), (61), (62) and (63):

$$\mathrm{k}_{47}^{*} = \mathrm{k}_{46}^{*} \tag{60}$$

$$\frac{\mathrm{B}_{47}^{*}}{\mathrm{B}_{47}} = \frac{\mathrm{B}_{46}^{*}}{\mathrm{B}_{46}} \tag{61}$$

$$\mathrm{x}_{1} = \frac{\mathrm{B}_{47}^{*}}{\mathrm{B}_{47}^{*}} = \frac{\mathrm{B}_{46}}{\mathrm{B}_{46}} \tag{62}$$

$$\mathrm{B}_{47} - \mathrm{x}_{1} \cdot \mathrm{B}_{46} = 0 \tag{63}$$

where:
k_{47}^{*} – the value of the exergy cost of net electricity from Generator 1,
k_{46}^{*} – the value of exergy cost of heat generated due to the losses in Generator 1,
B_{47} – the value of the exergy of net electricity from Generator 1,
B_{46} – the value of exergy of heat generated due to the losses in Generator 1,
B_{47}^{*} – the cumulative value of exergy needed to produce a certain amount exergy of net electricity from Generator 1,
B_{46}^{*} – the cumulative value of the exergy necessary to produce a certain amount of heat generated due to the losses in Generator 1,
x_{16} – exergy cost allocation coefficient for component 35.

It must be noticed that heat generated due to the losses in the generator 1 is a heat lost to the environment and what is more heat of rather low temperature and thus value of exergy flow of that (B_{46}) heat can be appointed value of 0 kW. To avoid dividing by 0 that heat was appointed a close to zero value of 1 kW. That exception applies only to heat generated and lost to the environment. Correlations for electricity (B_{47} and B_{48}, B_{47} and B_{49},) are calculated in the standard way.

The same rule and thus way of calculation applies to pairs of streams: B_{47} and B_{48}, B_{47} and B_{49}, as well as to Component 36 - Generator 2 with its 5 pairs of streams:

- B_{53} and B_{52},
- B_{53} and B_{54},
- B_{53} and B_{55},
- B_{53} and B_{56},
- B_{53} and B_{57}.

Applying the above method exergy cost allocation coefficients x_{17}, x_{18} are obtained from component 35 and coefficients x_{19}, x_{20}, x_{21}, x_{22}, x_{23}, from component 36.

Table 13 Values of calculated exergy cost allocation coefficients for selected components in the reference and operational state.

Component i	Exergy cost allocation coefficient	Exergy cost allocation coefficients value	
		Reference state x_0	Operational state x_1
2	$x_1=B_{45}/B_{38}$	0.930	0.938
18	$x_2=B_{15}/B_{16}$	1.027	1.025
19	$x_3=B_{16}/B_{18}$	1.034	1.031
20	$x_4=B_{18}/B_{21}$	1.314	1.327
22	$x_5=B_{21}/B_{23}$	1.024	1.023
23	$x_6=B_{23}/B_{24}$	1.003	1.003
24	$x_7=B_{24}/B_{26}$	1.045	1.045
25	$x_8=B_{26}/B_{28}$	1.124	1.123
26	$x_9=B_{28}/B_{31}$	1.027	1.027
28	$x_{10}=B_{31}/B_{32}$	1.046	1.045
27	$x_{11}=B_{30}/B_{39}$	0.363	0.359
21	$x_{12}=B_{36}/B_{20}$	0.024	0.024
7	$x_{13}=B_{5}/B_{6}$	1.645	1.622
8	$x_{14}=B_{8}/B_{9}$	3.976	3.674
11	$x_{15}=B_{9}/B_{14}$	33.615	33.099
35	$x_{16}=B_{47}/B_{46}$	50807.000	51987.000
35	$x_{17}=B_{47}/B_{48}$	13.210	12.717
35	$x_{18}=B_{47}/B_{49}$	384.902	393.841
36	$x_{19}=B_{53}/B_{52}$	15050.150	14240.843
36	$x_{20}=B_{53}/B_{54}$	51.489	43.590
36	$x_{21}=B_{53}/B_{55}$	1529.487	1430.234
36	$x_{22}=B_{53}/B_{56}$	194.874	180.630
36	$x_{23}=B_{53}/B_{57}$	1205.942	1124.869

The obtained results allow to supplement the matrix with additional equations in order to construct a square matrix $\mathbf{A_k}$ of the coefficients of the exergy cost balance equations, which is presented in Appendix A4 for each of the states of work.

The tables presented in Appendix A4 additionally allow to determine the cumulative exergy cost for particular streams in the system.

For this purpose, a mathematical operation should be performed consisting in the reversal of the matrix $\mathbf{A_k}$ to the form $(\mathbf{A_k})^{-1}$, and then multiplied by the column vector Y *, which is to the right of the discussed matrix $\mathbf{A_k}$. The method for the calculation of the cumulative value of the exergy cost of the selected stream is given by the formula (64):

$$B^{*} = (\mathbf{A_k})^{\mathbf{-1}} \cdot Y^{*} \tag{64}$$

where:

B^{*} – the cumulative value of the exergy cost of the stream,

$(\mathbf{A_k})^{\mathbf{-1}}$ – inverted matrix of system coefficients of exergy cost balance equations,

Y^{*} – column vector in the form $\begin{bmatrix} 0 \\ \omega_e \\ 0 \end{bmatrix}$.

Table 14 and

Table 15 present the exergy values, exergy costs as well as unit exergy costs of streams separated in the analysed CCGT system, obtained as a result of calculations. Matrices $\mathbf{(A_k)^{-1}}$ being a part of calculations are presented in Appendix A5.

Table 14 Values of exergy, exergy costs and specific exergy costs for all streams in reference state x_0

Stream number j	Stream type	Exergy cost B*	Exergy B	Specific exergy cost kj*
1	Air	3067.5	3067.5	1.00
2	Fuel	145266.2	142796.8	1.02
3	Fuel	140241.6	140241.6	1.00
4	Water	29.8	29.8	1.00
5	Steam	27828.4	17743.8	1.57
6	Steam	16916.2	10786.0	1.57
7	Steam	6890.0	4161.5	1.66
8	Steam	23806.2	14946.4	1.59
9	Steam	5986.9	3758.8	1.59
10	Sea Water	20303.2	17738.0	1.15
11	Sea Water	14494.5	14181.4	1.02
12	Sea Water	20303.2	16755.4	1.21
13	Sea Water	13950.6	13950.6	1.00
14	Water	178.1	111.8	1.59
15	Flue Gas	76962.1	59541.5	1.29
16	Flue Gas	74923.3	57964.2	1.29
17	Steam	25789.6	16367.8	1.58
18	Flue Gas	72490.5	56082.0	1.29
19	Steam	23925.4	15197.4	1.57
20	Steam	23356.8	14835.5	1.57
21	Flue Gas	55175.8	42686.6	1.29
22	Water/Steam	6610.7	3838.0	1.72
23	Flue Gas	53902.1	41701.2	1.29
24	Flue Gas	53722.3	41562.1	1.29
25	Water/Steam	5337.0	2945.8	1.81
26	Flue Gas	51432.6	39790.7	1.29
27	Steam	6710.2	4118.3	1.63
28	Flue Gas	45777.0	35415.2	1.29
29	Water	3958.2	1971.1	2.01
30	Water	1054.6	525.0	2.01
31	Flue Gas	44558.0	34472.2	1.29
32	Flue Gas	42607.4	32963.1	1.29
33	Water	3047.3	1499.4	2.03
34	Water	2739.2	1188.9	2.30

35	Water	2147.4	959.8	2.24
36	Steam	568.6	361.2	1.57
37	Water	196.7	113.5	1.73
38	Flue Gas	76962.1	59826.5	1.29
39	Water	2903.6	1445.5	2.01
40	Water	2716.0	1182.2	2.30
41	Steam	27828.4	17817.6	1.56
42	Steam	6890.0	4204.2	1.64
43	Water	196.4	113.5	1.73
44	Make-up water	0.3	0.3	1.00
45	GT Shaft power	71573.9	55638.0	1.29
46	Heat from G1	1.3	1.0	1.31
47	Net electricity from G1	66376.8	50807.0	1.31
48	Electricity to fuel compressor	5024.6	3846.0	1.31
49	Auxiliary of gas turbine	172.5	132.0	1.31
50	Shaft power from ST group 1	10912.2	6018.0	1.81
51	Shaft power from ST group 2	17819.3	9864.0	1.81
52	Heat from G2	1.9	1.0	1.86
53	Net electricity from G2	28002.4	15050.2	1.86
54	Electricity to Pump 13	543.9	292.3	1.86
55	Electricity to Pump 16	18.3	9.8	1.86
56	Electricity to Pump 30	143.7	77.2	1.86
57	Electricity to Pump 31	23.2	12.5	1.86

Table 15 Values of exergy, exergy costs and specific exergy costs for all streams in operational statate x_1

Stream number j	Stream type	Exergy cost B*	Exergy B	Specific exergy cost kj*
1	Air	3067.5	3067.5	1.00
2	Fuel	145266.2	142796.8	1.02
3	Fuel	140241.6	140241.6	1.00
4	Water	29.8	29.8	1.00
5	Steam	27828.4	17743.8	1.57
6	Steam	16916.2	10786.0	1.57
7	Steam	6890.0	4161.5	1.66
8	Steam	23806.2	14946.4	1.59
9	Steam	5986.9	3758.8	1.59
10	Sea Water	20303.2	17738.0	1.15
11	Sea Water	14494.5	14181.4	1.02
12	Sea Water	20303.2	16755.4	1.21
13	Sea Water	13950.6	13950.6	1.00
14	Water	178.1	111.8	1.59
15	Flue Gas	76962.1	59541.5	1.29
16	Flue Gas	74923.3	57964.2	1.29
17	Steam	25789.6	16367.8	1.58
18	Flue Gas	72490.5	56082.0	1.29
19	Steam	23925.4	15197.4	1.57
20	Steam	23356.8	14835.5	1.57
21	Flue Gas	55175.8	42686.6	1.29
22	Water/Steam	6610.7	3838.0	1.72
23	Flue Gas	53902.1	41701.2	1.29
24	Flue Gas	53722.3	41562.1	1.29
25	Water/Steam	5337.0	2945.8	1.81
26	Flue Gas	51432.6	39790.7	1.29
27	Steam	6710.2	4118.3	1.63
28	Flue Gas	45777.0	35415.2	1.29
29	Water	3958.2	1971.1	2.01
30	Water	1054.6	525.0	2.01
31	Flue Gas	44558.0	34472.2	1.29
32	Flue Gas	42607.4	32963.1	1.29
33	Water	3047.3	1499.4	2.03
34	Water	2739.2	1188.9	2.30
35	Water	2147.4	959.8	2.24
36	Steam	568.6	361.2	1.57
37	Water	196.7	113.5	1.73
38	Flue Gas	76962.1	59826.5	1.29
39	Water	2903.6	1445.5	2.01

Stream number j	Stream type	Exergy cost B*	Exergy B	Specific exergy cost kj*
40	Water	2716.0	1182.2	2.30
41	Steam	27828.4	17817.6	1.56
42	Steam	6890.0	4204.2	1.64
43	Water	196.4	113.5	1.73
44	Make-up water	0.3	0.3	1.00
45	GT Shaft power	71573.9	55638.0	1.29
46	Heat from G1	1.3	1.0	1.31
47	Net electricity from G1	66376.8	50807.0	1.31
48	Electricity to fuel compressor	5024.6	3846.0	1.31
49	Auxiliary of gas turbine	172.5	132.0	1.31
50	Shaft power from ST group 1	10912.2	6018.0	1.81
51	Shaft power from ST group 2	17819.3	9864.0	1.81
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55	Electricity to Pump 16	18.3	9.8	1.86
56	Electricity to Pump 30	143.7	77.2	1.86
57	Electricity to Pump 31	23.2	12.5	1.86

Analysing Table 14 and

Table 15, it can be noticed that exergy costs both in the reference and operational states increase as the process progresses, so the farther in the chain of irreversible changes the stream has a higher unit exergy cost.

Taking into account the above results, it is possible to easily determine the cumulated exergy costs of fuel streams supplying selected components and product streams leaving them. Therefore, it is necessary to recall $\mathbf{A_F}$ fuels and $\mathbf{A_P}$ products, previously presented in Appendices A2 and A3.

In the case of fuels, the column vector of their cumulative exergy values takes the form as shown in formula (65):

$$\mathrm{F_B^*} = \mathbf{A_F} \cdot \mathrm{Y_B^*} \tag{65}$$

where:
$\mathrm{F_B^*}$ – column vector of cumulated fuel exergy,
$\mathbf{A_F}$ – fuel matrix,
$\mathrm{Y_B^*}$ – column vector of the values of cumulated exergy costs of system streams.

On the other hand, in the case of products, the column vector of values of their cumulated exergy is expressed by the formula (66):

$$\mathrm{P_B^*} = \mathbf{A_P} \cdot \mathrm{Y_B^*} \tag{66}$$

where:
$\mathrm{P_B^*}$ – column vector of cumulated product exergy,
$\mathbf{A_P}$ – product matrix,
$\mathrm{Y_B^*}$ – column vector of the values of cumulated exergy costs of system streams.

Additionally, it is possible to determine the exergy cost of fuel or product, which was shown on the basis of formulas (67) and (68). Hence, the exergy cost of fuel is given by the formula (67):

$$\mathrm{k_F^*} = \frac{\mathrm{F_B^*}}{\mathrm{F_B}} \tag{67}$$

where:
$\mathrm{k_F^*}$ – exergy cost of the fuel stream,
$\mathrm{F_B^*}$ – cumulative exergy of the fuel stream,
$\mathrm{F_B}$ – fuel exergy flow.

In turn, the exergy cost of the product is expressed by the formula (68):

$$\mathrm{k_P^*} = \frac{\mathrm{P_B^*}}{\mathrm{P_B}} \tag{68}$$

where:
k_P^* – exergy cost of the product stream,
$\mathrm{P_B^*}$ – cumulative exergy of the product stream,
$\mathrm{P_B}$ – product exergy flow.

Finally, the exergy cost for the selected component can be calculated in two ways, which is presented below in the form of a formula (69). This allows to check whether the results of the calculations performed converge, and thus whether they have been carried out in a correct manner.

The exergy cost of a given device is calculated from the formula (69):

$$k = \frac{k_P^*}{k_F^*} = \frac{F_B}{P_B} \tag{69}$$

where:
k – exergy cost of the selected component,
k_P^* – exergy cost of the product stream of a given component,
k_F^* – exergy cost of the fuel stream of a given component,
F_B – fuel exergy flow,
P_B – product exergy flow.

Finally, Table 16 and Table 18 summarize the results of the calculations. For each component, the values of exergy flows of fuels and products, cumulative exergy costs of fuels and products, specific costs of fuel and product exergy, as well as total costs determined in two ways for the reference and operational status are presented. The red colour indicates the final values of the exergy costs of the components obtained by two methods in order to check the correctness of the calculations.

Table 16 The values of streams, cumulative stream values and exergy costs of fuels and products of individual components for the reference state x_0.

Component	**F_B, kW**	**F_B^*, kW**	**k_F^***	**P_B, kW**	**P_B^*, kW**	**k_P^***	**k**	**k**
2	146026.1	148536.0	1.02	115464.5	148536.0	1.29	1.26	1.26
3	3846.0	5024.6	1.31	2555.2	5024.6	1.97	1.51	1.51
6	17817.6	27828.4	1.56	17743.8	27828.4	1.57	1.00	1.00
7	6957.8	10912.2	1.57	6018.0	10912.2	1.81	1.16	1.16
8	11187.7	17819.3	1.59	9864.0	17819.3	1.81	1.13	1.13
9	14947.6	23806.2	1.59	14946.4	23806.2	1.59	1.00	1.00
10	4204.2	6890.0	1.64	4161.5	6890.0	1.66	1.01	1.01
11	3647.0	5808.8	1.59	3556.7	5808.8	1.63	1.03	1.03
12	17738.0	20303.2	1.15	16755.4	20303.2	1.21	1.06	1.06
13	292.3	543.9	1.86	230.8	543.9	2.36	1.27	1.27
16	9.8	18.3	1.86	1.7	18.3	11.02	5.92	5.92
17	59826.5	76962.1	1.29	59541.5	76962.1	1.29	1.00	1.00
18	1577.3	2038.8	1.29	1449.8	2038.8	1.41	1.09	1.09
19	1882.1	2432.8	1.29	1532.3	2432.8	1.59	1.23	1.23
20	13395.5	17314.7	1.29	11359.4	17314.7	1.52	1.18	1.18
21	15197.4	23925.4	1.57	15196.6	23925.4	1.57	1.00	1.00
22	985.4	1273.7	1.29	892.2	1273.7	1.43	1.10	1.10
23	139.1	179.8	1.29	86.0	179.8	2.09	1.62	1.62
24	1771.4	2289.7	1.29	1446.5	2289.7	1.58	1.22	1.22
25	4375.5	5655.6	1.29	3593.2	5655.6	1.57	1.22	1.22
26	943.0	1218.9	1.29	782.2	1218.9	1.56	1.21	1.21
27	1971.1	3958.2	2.01	1970.5	3958.2	2.01	1.00	1.00
28	1509.1	1950.7	1.29	846.3	1950.7	2.31	1.78	1.78
30	77.2	143.7	1.86	53.8	143.7	2.67	1.43	1.43
31	12.5	23.2	1.86	6.7	23.2	3.47	1.87	1.87
32	1321.0	2716.0	2.06	1182.2	2716.0	2.30	1.12	1.12
34	113.8	196.7	1.73	113.5	196.7	1.73	1.00	1.00
35	55638.0	71573.9	1.29	54785.0	71573.9	1.31	1.02	1.02
36	15882.0	28731.5	1.81	15442.0	28731.5	1.86	1.03	1.03

Table 17 The values of streams, cumulative stream values and exergy costs of fuels and products of individual components for the operational state x_1.

Component	**F_B, kW**	**F_B^*, kW**	**k_F^***	**P_B, kW**	**P_B^*, kW**	**k_P^***	**k**	**k**
2	149265.7	152021.7	1.02	117953.2	152021.7	1.289	1.27	1.27
3	4088.0	5350.4	1.31	2635.2	5350.4	2.03	1.55	1.55
6	18220.1	28621.7	1.57	18144.6	28621.7	1.577	1.00	1.00
7	6958.6	10976.6	1.58	5753.0	10976.6	1.908	1.21	1.21
8	11198.8	17903.8	1.60	9339.0	17903.8	1.917	1.20	1.20
9	15394.7	24598.9	1.60	15386.5	24598.9	1.599	1.00	1.00
10	4251.9	6953.8	1.64	4208.7	6953.8	1.652	1.01	1.01
11	4061.2	6492.8	1.60	3718.0	6492.8	1.746	1.09	1.09
12	18524.0	21718.4	1.17	18403.1	21718.4	1.18	1.01	1.01
13	326.7	643.2	1.97	223.6	643.2	2.876	1.46	1.46
16	10.0	19.6	1.97	1.7	19.6	11.436	5.81	5.81
17	60875.2	78457.8	1.29	60715.5	78457.8	1.292	1.00	1.00
18	1480.0	1912.5	1.29	1482.5	1912.5	1.29	1.00	1.00
19	1791.2	2314.6	1.29	1566.9	2314.6	1.477	1.14	1.14
20	14143.8	18276.9	1.29	11614.2	18276.9	1.574	1.22	1.22
21	15539.3	24986.7	1.61	15538.8	24986.7	1.608	1.00	1.00
22	971.4	1255.3	1.29	912.4	1255.3	1.376	1.06	1.06
23	141.2	182.4	1.29	86.9	182.4	2.098	1.62	1.62
24	1813.6	2343.6	1.29	1479.3	2343.6	1.584	1.23	1.23
25	4418.6	5709.8	1.29	3634.0	5709.8	1.571	1.22	1.22
26	957.4	1237.1	1.29	797.3	1237.1	1.552	1.20	1.20
27	2009.1	4017.2	2.00	2009.2	4017.2	1.999	1.00	1.00
28	1502.0	1940.9	1.29	850.3	1940.9	2.283	1.77	1.77
30	78.8	155.2	1.97	55.1	155.2	2.819	1.43	1.43
31	12.7	24.9	1.97	6.8	24.9	3.656	1.86	1.86
32	1346.9	2755.2	2.05	1205.0	2755.2	2.286	1.12	1.12
34	128.5	222.2	1.73	128.4	222.2	1.731	1.00	1.00
35	57078.0	73563.9	1.29	56207.0	73563.9	1.309	1.02	1.02
36	15092.0	28880.4	1.91	14669.0	28880.4	1.969	1.03	1.03

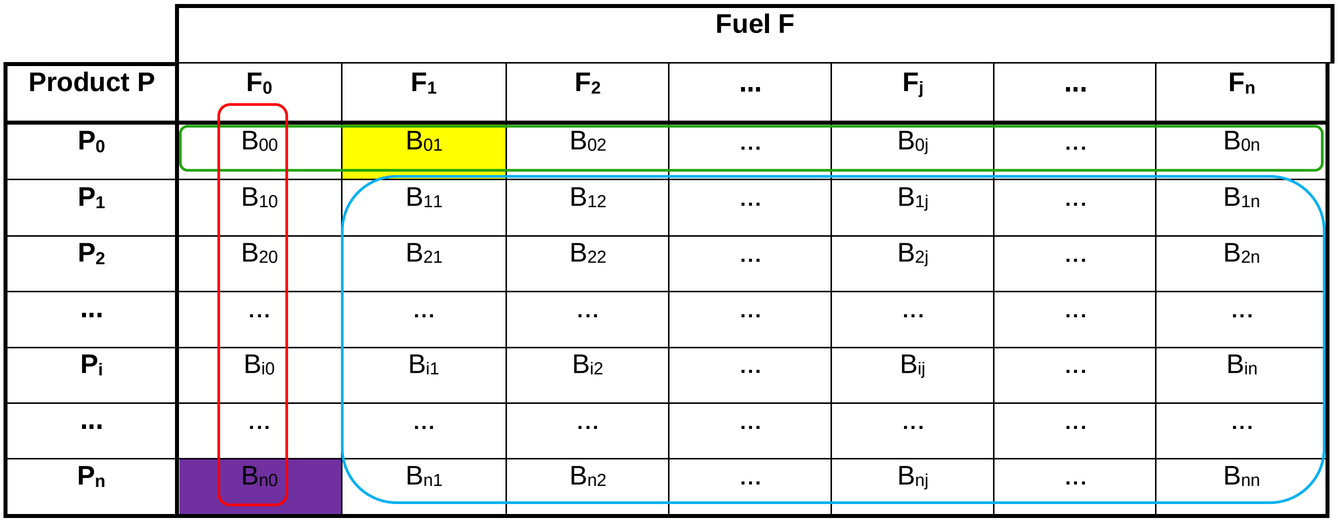
Analysing the results of calculations presented in the above tables, it can be concluded that they are correct. First of all, the exergy cost for each component calculated using two methods has the same value. In addition, none of the costs has a value less than one, and thus the value of fuel consumed is always greater than or equal to one.

5.5. Exergy diagnosis of the CCGT Plant

Diagnosis is a field dealing with the recognition and examination of changes in industrial facilities during their operation. Its task is to locate the place and the causes of the emerging imperfections in cycle, as well as to improve the efficiency of the irreversible process analysed. In addition, the diagnosis allows to check what is the impact of the malfunctioning device on the remaining components of the separated system, and to show how losses are generated in the cycle of thermodynamic processes in a given technological process. For this purpose, it is necessary to know the best about several operational states of the system, with one of these states being so called reference, and therefore working with the highest possible efficiency, and thus with limited losses. Other states, called operational, are most often created as a result of deterioration of the parameters of the reference condition. The reference state is thus a reference point in the thermoeconomic analysis with which the other operating conditions of the system can be compared [18].

The basis for conducting exergy diagnosis is to construct the so-called "Fuel - Product (F - P)" table. In the case of complex systems, it is an excellent tool illustrating how the exergy costs are distributed between individual components. So, one can easily tell which product of the "i=1" component is the fuel for the "i=2" component. However, this method requires knowing the value of the exergy cost as well as the way it is formed in the system. The table below shows a generalized, exemplary form of the table (F - P).

Table 18 An example of a generalized "Fuel - Product (F - P)" table



	Fuel F						
Product P	**F_0**	**F_1**	**F_2**	**...**	**F_j**	**...**	**F_n**
P_0	B_{00}	B_{01}	B_{02}	...	B_{0j}	...	B_{0n}
P_1	B_{10}	B_{11}	B_{12}	...	B_{1j}	...	B_{1n}
P_2	B_{20}	B_{21}	B_{22}	...	B_{2j}	...	B_{2n}
...	...	...	...	...	...	...	...
P_i	B_{i0}	B_{i1}	B_{i2}	...	B_{ij}	...	B_{in}
...	...	...	...	...	...	...	...
P_n	B_{n0}	B_{n1}	B_{n2}	...	B_{nj}	...	B_{nn}

As it can be noticed, the table (F-P) consists of the same number of rows and columns corresponding to the number of components that were isolated in the system. In addition, the number "0" indicates the component representing the environment - ambient outside the system boundary. For clarification - individual lines are partial values of exergy flows of products of selected components, while the columns are partial values of exergy flows of relevant components. For example, row P_0 means the values of streams of products supplied from outside the system boundary to the system being analysed. In turn, the F_0 column is the values of exergy flows of fuels supplied to the environment - beyond the system boundary from the system being diagnosed. Thus, the cells covered by the red loop are filled with the values of exergy flows that cross the system boundary, thus leaving the system. Cells inside the green loop are filled with exergy flow values that are supplied to the system from the outside, while inside the blue loop there are exergy flows present inside the analysed system, which are supplemented based on the matrix algorithm.

For example, in the cell marked with yellow colour in Table 18, an exergy flow B_{01} should be inserted, informing that it is the product of the component "0" - therefore of the environment, and at the same time the fuel for the component "1". Thus, the cell marked in purple should be supplemented with the B_{n0} exergy flow, which says that it is a product constituting the component "n", which is also a fuel for the component "0", so for the environment outside the system boundary. After summing up all partial values of fuels and products, i.e. columns and rows, respectively, the total amount of fuel or product entering or leaving a specific component of the system is obtained, as described in (70) and (71) [15] [18].

$$\mathrm{F_i} = \sum_{\mathrm{j}=0}^{\mathrm{n}} \mathrm{B_{ji}} \tag{70}$$

where:
$\mathrm{F_i}$ – the total fuel exergy flow of the i-th component,
$\mathrm{B_{ji}}$ – the partial value of the exergy flow supplied to the i-component from the j-th component,
n – number of components.

$$\mathrm{P_i} = \sum_{\mathrm{j}=0}^{\mathrm{n}} \mathrm{B_{ij}} \tag{71}$$

where:
$\mathrm{P_i}$ – the total product exergy flow of the i-th component,
$\mathrm{B_{ij}}$ – the partial value of the exergy flow of the i-th component supplied to the component j-th,
n – number of components.

In the case of complicated cycles "Fuel - Product" matrix as shown in Table 18 can be determined based on the matrix algorithm. This algorithm is explained in nine steps in subchapters from 5.5.1 to 5.5.9.

5.5.1. Step 1

In the first place, a matrix of the system coefficients of equations for the exergy cost **A$_z$** should be created, for each of the work states - reference x$_0$ and operational x$_1$, which occurs in the form [19]:

$$\begin{bmatrix} \mathbf{A_p} \\ \boldsymbol{\alpha}_\mathbf{e} \\ \boldsymbol{\alpha}_\mathbf{x} \end{bmatrix}$$

Then the matrix **A$_z$** has to be inverted, which results in the matrix **(A$_z$)$^{-1}$** in the form [19]:

$$\begin{bmatrix} \mathbf{A_p^{-1}} & \boldsymbol{\alpha}_\mathbf{e}^{-1} & \boldsymbol{\alpha}_\mathbf{x}^{-1} \end{bmatrix}$$

The above matrices, both for reference x$_0$ and operational x$_1$ state, are shown in Appendices A6 and A7 respectively.

5.5.2. Step 2

Then, having the appropriate matrices presented in Appendices A6 and A7, one can proceed to the determination of the $\langle\mathbf{FP}\rangle$ table representing the division of values of individual exergy flows between the i-th fuel of the component and the product of the j-th component. Therefore, it is needed to multiply the matrix of fuels **A$_F$** with reversed product matrix **(A$_p$)$^{-1}$**, which is shown by the formula number (72) [19]:

$$\mathbf{A_F} \cdot (\mathbf{A_P})^{-1} = \langle\mathbf{FP}\rangle \tag{72}$$

where:
$\mathbf{A_F}$ – fuel matrix,
$(\mathbf{A_P})^{-1}$ – inverted products matrix,
$\langle\mathbf{FP}\rangle$ – matrix of division of exergy flows of fuels and products between system components.

For the reference and operational state, calculated $\langle\mathbf{FP}\rangle$ tables are presented in Appendix A8.

5.5.3. Step 3

Further, matrices $\langle\mathbf{FP}\rangle$ should be transposed to $\langle\mathbf{FP}\rangle^{\mathbf{t}}$ what is presented in Appendix A9 [19].

5.5.4. Step 4

In the next step one should fill the appropriate area within the blue colour in Table 18 showing the generalized form of the "Fuel - Product" table. This can be done by multiplying the matrix $\langle\mathbf{FP}\rangle^{\mathbf{t}}$ and the column vector of the product streams values of each of the components of the P_B system, which is shown in equation (73) [19]:

$$\mathbf{F_x} = \langle\mathbf{FP}\rangle^{\mathbf{t}} \cdot \mathrm{P_B} \tag{73}$$

where:
$\mathbf{F_x}$ – matrix of partial values of fuels and products,
$\langle\mathbf{FP}\rangle^{\mathbf{t}}$ – transposed matrix of division of exergy flows of fuels and products,
$\mathrm{P_B}$ – a column vector for the values of exergy flows of products of individual components.

Hence, for the two operational states, the $\mathbf{F_x}$ matrices presented in Appendix A10 are obtained.

Finally, the matrix F_x must be supplemented with an additional component "0" representing the external environment of the system - the environment outside the system boundary of the power plant, as well as exergy flows constituting fuels and products of this component. Thus, finally, "Fuel - Product (F - P)" tables are obtained, which are presented in Appendix A11 for both states of the CCGT system. In these tables, additional rows and columns have been added to sum the total amount of fuel and product for the selected component.

Generally, the purpose of the performed diagnosis is to show how the exergy cost of a useful product is formed in the irreversible transformation cycle, in addition how the consumption of exergy of fuels supplied to individual components changes as a result of thermodynamic changes, and a graphic representation of malfunctions and dysfunctions of devices in the analysed system.

The matrices presented in Appendix A11, representing fuel and product flow matrices between components, are necessary for this purpose.

When conducting a diagnosis analysis, one should start by determining the exergy consumption of each component. The tables below present a stream of fuel exergy, product as well as exergy cost calculated as the ratio of the exergy of fuel to the exergy of product.

Table 19 Comparison of the values of exergy flows of fuels, products as well as exergy costs for individual components in the reference state x_0

Component i	F	P	I	k
2	146026.1	115464.5	30561.6	1.27
3	3846.0	2555.2	1290.8	1.51
6	17817.6	17743.8	73.8	1.00
7	6957.8	6018.0	939.8	1.16
8	11187.7	9864.0	1323.7	1.13
9	14947.6	14946.4	1.1	1.00
10	4204.2	4161.5	42.7	1.01
11	3647.0	3556.7	90.3	1.03
12	17738.0	16755.4	982.6	1.06
13	292.3	230.8	61.5	1.27
16	9.8	1.7	8.2	5.92
17	59826.5	59541.5	285.0	1.01
18	1577.3	1449.8	127.5	1.09
19	1882.1	1532.3	349.8	1.23
20	13395.5	11359.4	2036.1	1.18
21	15197.4	15196.6	0.8	1.00
22	985.4	892.2	93.2	1.10
23	139.1	86.0	53.1	1.62
24	1771.4	1446.5	325.0	1.23
25	4375.5	3593.2	782.2	1.22
26	943.0	782.2	160.8	1.21
27	1971.1	1970.5	0.5	1.00
28	1509.1	846.3	662.8	1.78
30	77.2	53.8	23.4	1.43
31	12.5	6.7	5.8	1.87
32	1321.0	1182.2	138.8	1.12
34	113.8	113.5	0.2	1.00
35	55638.0	54785.0	853.0	1.02
36	15882.0	15442.0	440.0	1.03

Table 20 Comparison of the values of exergy flows of fuels, products as well as exergy costs for individual components in the operational state x_1

Component i	F	P	I	k
2	149265.7	117953.2	31312.5	1.27
3	4088.0	2635.2	1452.8	1.55
6	18220.1	18144.6	75.5	1.00
7	6958.6	5753.0	1205.6	1.21
8	11198.8	9339.0	1859.8	1.20
9	15394.7	15386.5	8.2	1.00
10	4251.9	4208.7	43.2	1.01
11	4061.2	3718.0	343.2	1.09
12	18524.0	18403.1	120.9	1.01
13	326.7	223.6	103.1	1.46
16	10.0	1.7	8.2	5.81
17	60875.2	60715.5	159.7	1.00
18	1480.0	1482.5	-2.6	1.00
19	1791.2	1566.9	224.3	1.14
20	14143.8	11614.2	2529.6	1.22
21	15539.3	15538.8	0.4	1.00
22	971.4	912.4	59.0	1.07
23	141.2	86.9	54.2	1.62
24	1813.6	1479.3	334.3	1.23
25	4418.6	3634.0	784.6	1.22
26	957.4	797.3	160.1	1.20
27	2009.1	2009.2	-0.1	1.00
28	1502.0	850.3	651.7	1.77
30	78.8	55.1	23.8	1.43
31	12.7	6.8	5.8	1.86
32	1346.9	1205.0	141.9	1.12
34	128.5	128.4	0.1	1.00
35	57078.0	56207.0	871.0	1.02
36	15092.0	14669.0	423.0	1.03

Two components in the Table 20 – number 18 and 27 has Fuels lower than Product but values of exergy are close to each other. That difference can be accepted as it is just 2 ‰ error for the higher inconsistency.

5.5.5. Step 5

Then, using the following formula (74) and based on matrix $\mathbf{F}_x$, one should construct a matrix $\langle \mathbf{KP} \rangle$ representing specific consumption of exergy of individual devices defined as the amount of exergy that one component requires from the other to obtain a unit of a usable product what is shown in equation (74).

$$k_{ij} = \frac{B_{ij}}{P_j} \tag{74}$$

where:
k_{ij} – specific exergy consumption,
B_{ij} – the exergy of the i-th component brought to the j-th component,
P_j – product of j-th component.

The $\langle \mathbf{KP} \rangle$ matrices for the reference and operational states are summarized in Appendix A12.

5.5.6. Step 6

Another step necessary to perform the diagnosis is the subtraction of the $\langle \mathbf{KP} \rangle$ matrix obtained for the reference state from the same matrix obtained for the operational state. As a result, a matrix $\Delta\langle \mathbf{KP} \rangle$ is presented in Appendix A13.

5.5.7. Step 7

After adding up the values present in each column, one can easily obtain the total difference of the exergy unit cost of the selected component as a result of changes in the working conditions from the reference to the operational state, i.e. as a result of deterioration. These values are presented in Table 21.

The same results can be obtained by subtracting from each other the unit cost of exergy included in Table 19 and Table 20.

Table 21 Difference of specific consumption of exergy of individual components as a result of changes in working conditions

Component i	Δk_i	Component i	Δk_i
2	0.001	20	0.039
3	0.092	21	0.000
6	0.000	22	-0.040
7	0.053	23	0.006
8	0.065	24	0.001
9	0.000	25	-0.002
10	0.000	26	-0.005
11	0.067	27	0.000
12	-0.012	28	-0.017
13	0.388	30	-0.003
16	-0.111	31	-0.009
17	-0.002	32	0.000
18	-0.090	34	-0.002
19	-0.085	35	0.000
		36	0.000

Analysing results from Table 21 one can deduct that after changing from reference to operational conditions exergy costs for some components has risen whereas for other components has dropped. The most significant changes that occurred, regarding exergy cost decrease are components: 16, 18, 19. However exergy cost of following components increased widely: 3, 7, 8 13. Summing up operation of steam turbine and fuel compressor had deteriorated while HRSG and condensate pump had improved their performance.

5.5.8. Step 8

To carry out further calculations related to diagnosis, it is necessary to determine the so-called product and irreversibility operators, and to use of the $\mathbf{U_D}$ unit matrix consisting of as many rows and columns as how many components the analysed system is built up. The $\mathbf{U_D}$ unitary matrix is shown in Appendix A14.

In turn, the product operator $\mathbf{IP}\rangle$ written in the matrix form is given in by the formula (75) [18]:

$$\mathbf{IP}\rangle = (\mathbf{U_D} - \langle\mathbf{KP}\rangle\,)^{-1} \tag{75}$$

where:
$\mathbf{IP}\rangle$ – product operator,
$\mathbf{U_D}$ – unitary matrix,
$\langle\mathbf{KP}\rangle$ – square matrix representing specific exergy consumption of selected components.

For reference and operational state, the product operator $\mathbf{IP}\rangle$ matrices are presented in Appendix A15.

Then it is possible to determine the operator of irreversibility, the matrix form of which is given by the formula (76):

$$\mathbf{II}\rangle = (\mathbf{K_D} - \mathbf{U_D}) \cdot \mathbf{IP}\rangle \tag{76}$$

where:
$\mathbf{II}\rangle$ – irreversibility operator,
$\mathbf{K_D}$ – diagonal matrix of values of specific exergy costs,
$\mathbf{U_D}$ – unitary matrix,
$\mathbf{IP}\rangle$ – product operator.

5.5.9. Step 9

The diagonal matrix $\mathbf{K_D}$ is obtained by using the $\mathbf{U_D}$ unitary matrix. In place of the cells supplemented with values equal to "1", the unit consumption values of exergy k are introduced, presented in Table 19 for the reference state and Table 20 for the operational state.

The diagonal matrix $\mathbf{K_D}$ and as a result the irreversibility operator $\mathbf{II}\rangle$ of the presented CCGT power plant are presented for two operational states (reference x_0, and operational x_1) in Appendix A16.

Completing the irreversibility operator matrices for both work states with an additional line representing the "0" component - external environment, a matrix can be obtained showing how the exergy cost of a product is determined at particular stages of electricity production. It should be remembered that the products for the "0" component, cutting through the system boundary, simultaneously supplying it, are burdened with the cost equal to 1. Thus, all the cells included in the line representing the environmental component should be filled with values equal to 1.

Therefore, matrices are obtained which show which component have highest impact on formation of exergy costs. They are attached in Appendix A17. In those matrices lowermost row shows accumulated exergy costs for all diagnosed components.

5.6. Results of exergy diagnosis of the CCGT Plant

As expected, comparing both tables from Appendix A17, it can be noticed that due to the introduced changes deteriorating the work of the CCGT power plant, accumulated exergy costs increased. The largest cost is observed in the case of a condensate pump. The smallest accumulated exergy cost is burdened with a component 12 which represent pipeline of seawater (throttling element), which is logical due to the fact that this element itself introduce small exergy losses is a part of short chain of exergy cost accumulation – sea water line. In that line sea water of accumulated exergy cost of 1 enters the system from outside the boundary and travels through the pump, condenser, pipeline and back outside the system boundary. However, sea water pump and condensate pump experience the highest cumulative cost increase due to change from reference to operational state. This is due to the fact of flow increase in these machines. Cumulative exergy cost increase in operational state for main devices (fuel compressor, gas turbine, steam turbine) mast be pointed out while cumulative exergy cost decrease for HRSG components what reflects changes in exergy costs described in chapter 4.2.

Exergy cost formation for all components in both operational and reference state are presented in Appendix A21.

The next stage of the thermoeconomic analysis is to calculate and graphic representate of "malfunctions" and "dysfunctions" for all components of the system. These concepts are based mainly on the distribution of the irreversibility increase occurring as a result of changes introduced to certain parameters:

- caused by the work of the device itself,
- those that result from an actions of other components.

Therefore, following apportionment may be concluded:

- Malfunctions - endogenous factors influencing the increase of the irreversibility value associated with a given transformation occurring in the selected component. It is a deterioration of the operation of the device due to a change in its operating parameters, which increases its fuel exergy [18].
- Dysfunctions - exogenous factors, causing the need to increase the production of given components due to the deterioration of performance of other components. They reflect the increase in the irreversibility value occurring in a given component as a result of imperfect operation of other devices [18].

5.6.1. Malfunctions

Malfunctions in matrix form can be represented by the formula (77) [15]:

$$(\mathrm{MF})_{\mathrm{i-j}} = \Delta \mathrm{k}_{\mathrm{i-j}} \mathrm{P}_{\mathrm{j}}(\mathrm{x}_0) \tag{77}$$

where:
$(\mathrm{MF})_{\mathrm{i-j}}$ – malfunction resulting from the increase in specific exergy consumption,
$\Delta \mathrm{k}_{\mathrm{i-j}}$ – increase in specific exergy consumption,
$\mathrm{P}_{\mathrm{j}}(\mathrm{x}_0)$ – value of the exergy flow of the product in the reference state x_0.

The total malfunction for the selected component is calculated from the formula (78) [15]:

$$(\mathrm{MF})_{\mathrm{j}} = \sum_{\mathrm{i}=0}^{\mathrm{m}} \Delta \mathrm{k}_{\mathrm{i-j}} \mathrm{P}_{\mathrm{j}}(\mathrm{x}_0) = \sum_{\mathrm{i}=0}^{\mathrm{m}} (\mathrm{MF})_{\mathrm{i-j}} \tag{78}$$

where:
$(\mathrm{MF})_\mathrm{j}$ – total malfunction of the j^th component,
$(\mathrm{MF})_\mathrm{i-j}$ – malfunction resulting from the increase in specific exergy consumption,
$\Delta\mathrm{k}_\mathrm{i-j}$ – increase in specific exergy consumption,
$\mathrm{P_j}(\mathrm{x_0})$ – value of the exergy flow of the product in the reference state x_0,
i – component number,
m – number of components.

To determine the malfunction table, matrix $\Delta\langle\mathbf{KP}\rangle$ should be used as well as exergy flows of P products for each of the components of the analyzed system. The matrix of malfunction arises as a result of the multiplication of each cell of the $\Delta\langle\mathbf{KP}\rangle$ table by the corresponding stream of exergy of product P, including the environmental component with the number "0". The malfunctions matrix is presented in Appendix A18.

Analyzing the malfunctions matrix, it can be noticed that due to the introduced changes in the operating parameters, the components number 7 and 8 so the steam turbine, has deteriorated to the greatest extent. Other elements that can be characterized by high malfunction are steam condenser, fuel compressor and gas tubine. Interestingly, according to the data some components (parts of HRSG: 17, 18, 19, 22, 25, 26, 28), in operating condition has a negative malfunction value, which indicates that it improved its performance after introducing changes to the system (irreversibility in this component decreased). However a few components of HRSG are characterized by higher malfunction in operational state which is not high to the one extent – coponent number 20 which is evaporator with a drum. For this components malfunctions increased in operational state.

5.6.2. Dysfunctions

Dysfunction can be recorded using the following formula (79) [15]:

$$(\mathrm{DF})_\mathrm{j} = (\mathrm{k_j} - 1)\Delta\mathrm{P_j} \tag{79}$$

where:
$(\mathbf{DF})_\mathbf{j}$ – total dysfunction of j^th component,
$\mathrm{k_j}$ – specific exergy cost of j^th component,
$\Delta\mathrm{P_j}$ – increase of the exergy flow of the product for j^th component.

At the same time, the formula for dysfunction in the matrix form takes the form (80) [15]:

$$(\mathbf{DF}) = \mathbf{II}\rangle(\mathbf{x_1}) \cdot \Delta\langle\mathbf{KP}\rangle \cdot \mathbf{P}(\mathbf{x_0}) \tag{80}$$

where:
$(\mathbf{DF})$ – dysfunction,
$\mathbf{II}\rangle(\mathbf{x_1})$ – matrix of irreversibility operator for operational state x_1,
$\Delta\langle\mathbf{KP}\rangle$ – matrix representing difference between specific exergy consumptions,
$\mathbf{P}(\mathbf{x_0})$ – diagonal matrix of exergy values of products for the reference state x_0.

The matrices necessary for the final determination of the dysfunction matrix for the diagnosed CCGT system are presented in Appendix A19.

Finally, as a result of multiplying matrices presented in Appendix A19, the dysfunction matrix for the analyzed power plant takes the form presented in Appendix A20.

The method for calculating dysfunctions is based on equation (80) and is a matrix-based method. After adding each row of the matrix, the total dysfunction value for individual components is obtained. Summing up the column with the dysfunction values for the extracted components, the total dysfunction value of the analyzed system is obtained. Ultimately, one must sum up the results of each column and then sum up the resulting row (DI) and compare the results. As can be seen, the results obtained from summing of rows as well as columns are the same.

5.6.3. Results

A graphic representations of the malfunction and dysfunctions of the CCGT power plant are shown in the Figure 14 and Figure 15.

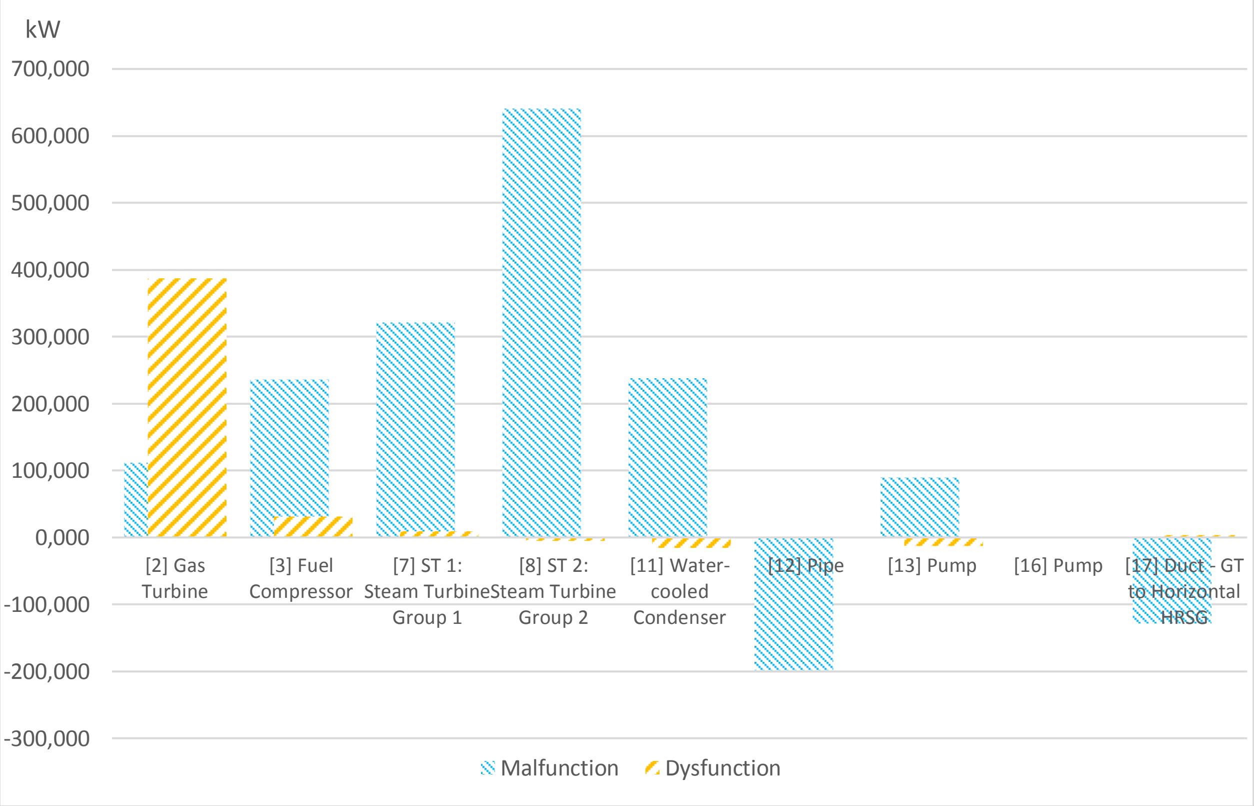


Figure 14 Malfunctions and dysfunctions chart of CCGT plant for selected components (i=2-17)

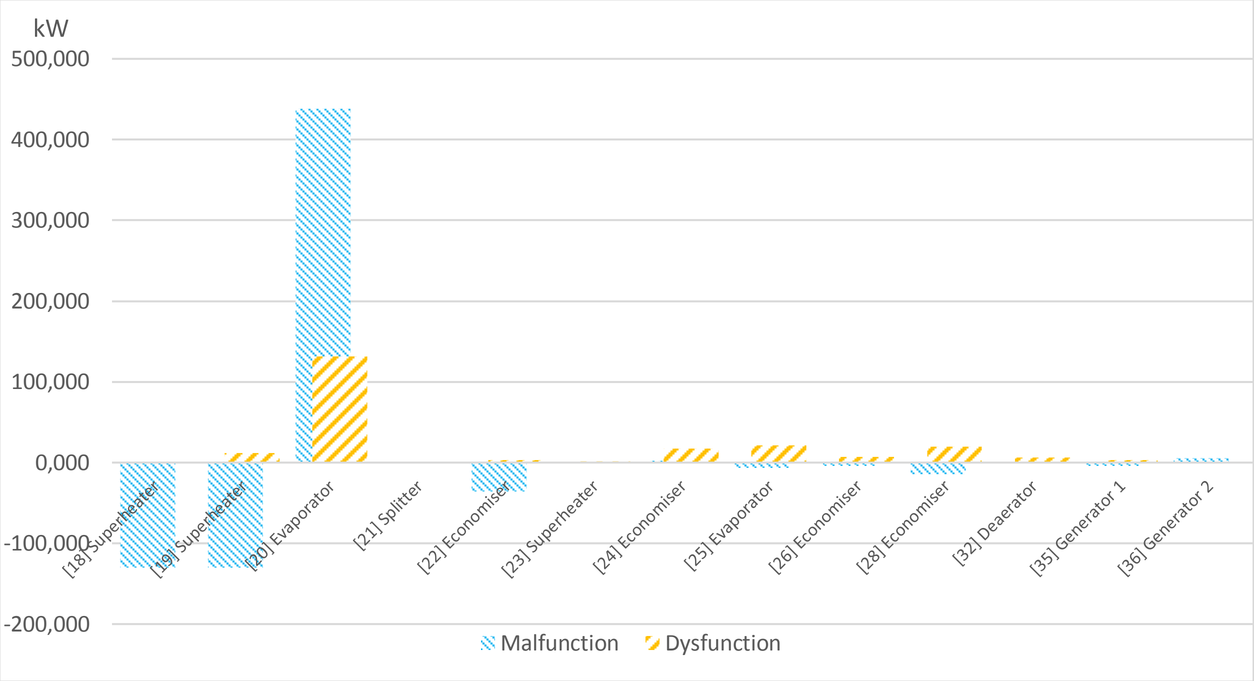


Figure 15 Malfunctions and dysfunctions chart of CCGT plant for selected components (i=18-36)

Analyzing Figure 14 and Figure 15 can be stated that as a result of changes in the operation of the system:

- Gas turbine, fuel compressor, steam turbine, condenser, sea water pump, high pressure boiler with drum (i=20) their performance in reference to an increase in the irreversibility of the processes taking place in them,
- Sea water pipeline, flue gas duct from gas turbine to HRSG, some of HRSG heat exchangers (i=18, 19, 21, 22, 25, 26, 28) have negative malfunction value which indicats that they work with less irreversibilities in operational state,
- Considering impact of other components on a given component, thus sum of exogenous factors affecting the component, with the highest negative impact are burdened: gas turbine, fuel gas compressor, high pressure boiler of HRSG (i=20), and high pressure economizer 2 (i=24), intermeditate pressure boiler (i=25) and low temperature economizer (i=28).

Finally calculations for increasing the consumption of fuel exergy for individual components, as well as the entire system can be done. The increment of the fuel exergy flow stream for a separated system in the general form results from the difference of the supplied fuel exergy flow in the operational and reference state which is given by the formula (81) [15]:

$$\Delta \mathrm{F_T} = \mathrm{F_T}(\mathrm{x_1}) - \mathrm{F_T}(\mathrm{x_0}) = 161081.2 - 157289.8 = 3791.4\ \mathrm{kW} \qquad (81)$$

where:
$\Delta \mathrm{F_T}$ – difference of fuel exergy flow supplied to the system,
$\mathrm{F_T}(\mathrm{x_1})$ – the fuel exergy flow supplied to the system in the operational state,
$\mathrm{F_T}(\mathrm{x_0})$ – the fuel exergy flow supplied to the system in the reference state.

In addition, there is a relationship (82):

$$\Delta F_T = \Delta P_T + \sum_{j=1}^{n} \Delta I_j \qquad (82)$$

where:
ΔF_T – difference of the fuel exergy flow supplied to the system,
ΔP_T – difference of the product exergy flow leaving the system,
ΔI_j – difference of the irreversibilities in the system,
j – component number,
n – number of components.

And then (83):

$$\Delta F_T = 2553.7 + 1237.7 = 3791.4 \text{ kW} \qquad (83)$$

Using the formulas (81) and (83) the results of fuel consumption for the CCGT system were obtained. It must therefore be said that results are reasonable due to the fact that different methods of calculation give the same values. Figure 16 graphically presents the differences of exergy of fuel delivered to the system from outside of the system boundary.

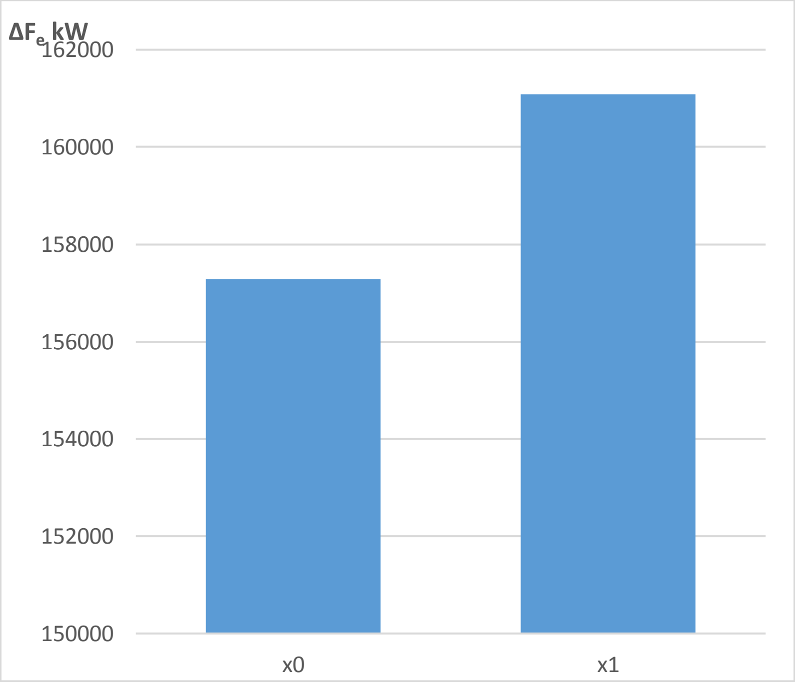


Figure 16 Differences in the consumption of fuel exergy supplying the whole system between the reference and the operational state of the CCGT plant

Figure 17 and Figure 18 in turn, compares the consumption of fuel exergy for individual components after the change of the operational state from reference x_0 to operational x_1.

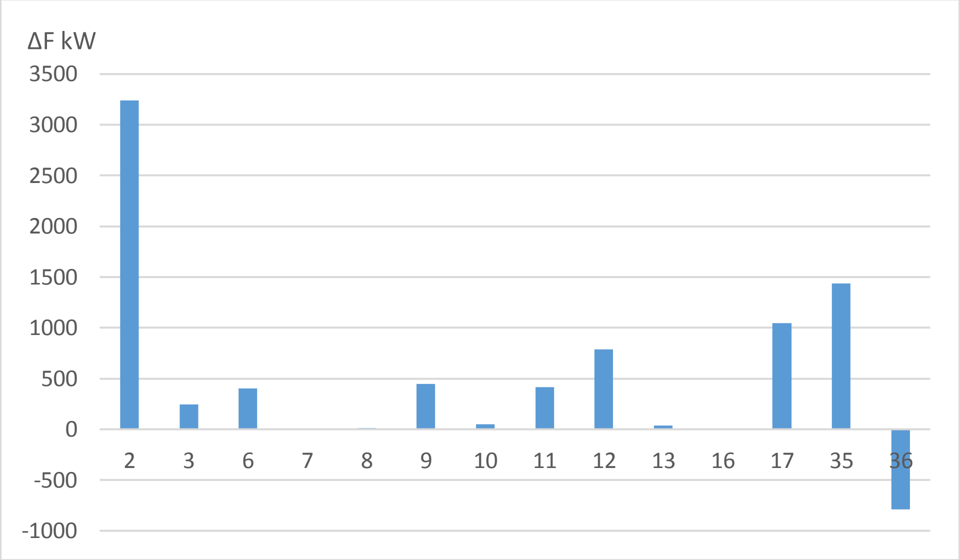


Figure 17 Differences in fuel exergy consumption for individual components (in it GT, ST) of analyzed CCGT plant

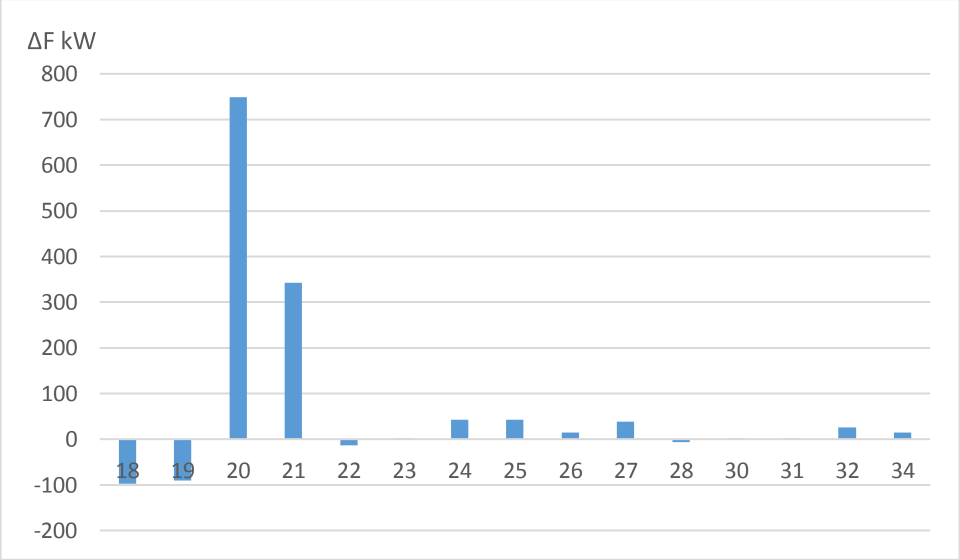


Figure 18 Differences in fuel exergy consumption for individual components (mainly HRSG) of analyzed CCGT plant

Referring to Figure 17 and Figure 18, it can be concluded that as a result of the introduced, the value of the exergy flow of fuel supplied to the system from outside the system boundary has increased. This is a result of the increase in the irreversibility value accompanying the processes taking place inside individual components. From the figures it can be clearly seen that highest increase of exergy consumption occurred for components: gas turbine, gas turbine generator and high-pressure boiler (i=20). There is no change in exergy delivered to steam turbine (i=7, 8) as steam parameters entering the turbine parts was set rigidly. However, impact of decreasing adiabatic efficiency of turbine parts results in change of turbine products what can be seen in Figure 14 as malfunction for components 7 and 8.

6. Thermoeconomic analysis of a CCGT plant integrated with LNG regasification

6.1. Description and presentation of the system

The subject of these analysis is Combined Cycle Gas Turbine Power Plant integrated with LNG regasification, whose scheme and thermodynamic model were designed in the THERMOFLEX 26 [1] software as presented in Figure 19.

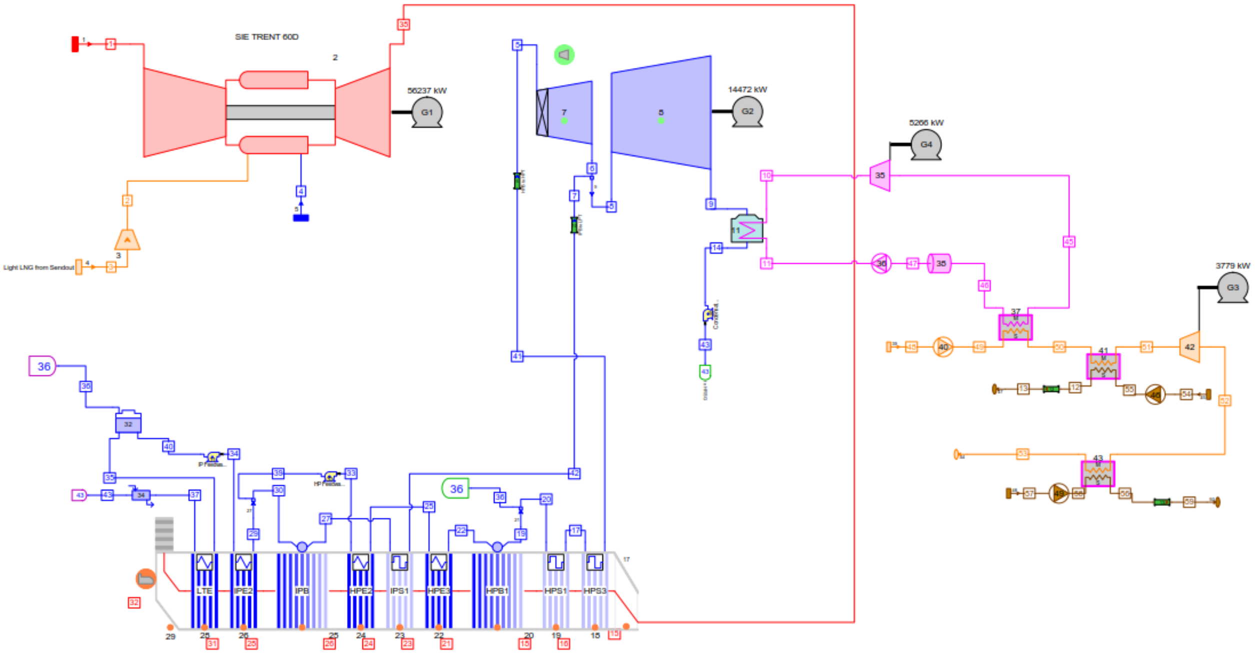


Figure 19 CCGT integrated with LNG regasyfication system presented in Thermoflex 26 [1]

THERMOFLEX [1] allows to create a mathematical model of the selected power unit. The structure of such a system consists in selecting and combining the appropriate components to obtain a complete system, as well as determining the initial thermodynamic parameters. Thanks to this, after the simulation, a ready set of parameters for all streams of the extracted unit is obtained. As can be seen in the figure above, the analysed power plant consists of 40 components and 60 streams. However, the method for exergy analysis requires more streams to be defined. They are showed shown in appendix B.

Appendix B presents a diagram of a simple gas and steam power plant modelled in the THERMOFLEX 26 [1] software with marked additional streams. After completing the drawing system can be described as consisting of 40 elements and 81 streams.

The table the presents the components included in the layout of CCGT with LNG regasification is presented in Appendix B1.

The discussed cycle is implemented based on the described devices. Presenting the simplified operation of a given system: a stream of air and natural gas is supplied to the combustion chamber of the gas turbine generating a combustible mixture, which then causes combustion of high temperature flue gases at increased pressure. These fumes are then directed to the gas turbine, where as a result of their expansion, mechanical power is generated on the shaft, resulting in driving the compressor and the generator. In addition to electricity generated at the terminals of the generator, from the gas turbine set, exhaust fumes are fed to the boiler (Heat Recovery Steam Generator), whose task is to heat the feedwater, evaporate it and overheat the steam generated, which is then fed to a steam turbine. In turn, in this component, as a result of steam expansion, mechanical power is generated that drives the generator, as well as low-temperature and low-pressure steam supplying the condenser. Condensate leaving the condenser goes to the feedwater pump, thus increasing the pressure. Water with increased pressure goes to the recovery boiler, thus closing the gas-steam cycle. However, heat from the condenser is not rejected to the environment but used to regasify liquefied natural gas. CCGT cycle and LNG cycle are interconnected by an ammonia cycle which serves a role in increasing thermodynamic efficiencies (reducing imperfections) of a whole plant by gradually reducing temperature difference (pinch) between LNG and steam condensate. What is more application of ammonia intermediate cycle is dictated by material and fluid properties. It is hard to find right fluid to suit that temperature range. The lowest cycle is LNG cycle which is similar to as-called in literature direct expansion + sea water heating regasification. The difference consists in utilizing additional heat supplied by ammonia cycle, coming from CCGT cycle.

6.2. Parameters of the system

Due to the fact that the thermoeconomic analysis is based on a comparison of the operational state of the given system with the reference state that works as effectively as possible, the following table lists the work parameters that have deteriorated, thus creating an operational state.

Table 22 List of parameters changed within the operational states of the analyzed system

Parameter	**Value**	
	Reference state x_0	**Operational state x_1**
Condenser pressure [bar]	0.040	0.050
1st stage steam turbine isentropic efficiency [%]	87.65	82.51
2nd stage steam turbine isentropic efficiency [%]	88.98	83.70
Min **Δ**T HRSG [K]	5	7
Pump [36] isentropic efficiency [%]	70.00	68.00
Pump [40] isentropic efficiency [%]	80.00	75.00
LNG turbine isentropic efficiency [%]	78.00	75.00

Referring to Table 22 two operating conditions were analysed, which differed among themselves: condenser pressure, internal efficiency of the steam turbine, isentropic efficiency of feed water pumps, minimum temperature difference in heat recover steam generator and LNG turbine isentropic efficiency. The purpose of the diagnosis was to check how the deterioration of these parameters in relation to the operational state influenced the operation of the discussed system.

Table 23 shows the molar composition of natural gas, which is the fuel for the analysed heat and power plant. Table 24 shows the molar composition of Liquified Natural Gas, which is being regasified in proposed plant. As a result of the simulation, data on the shares of individual exhaust were obtained as shown below in Table 25. Knowledge of the shares of individual exhaust components is necessary to determine the chemical and physical exergue emissions. The situation is similar when calculating the physical exergy of fuel.

Table 23 The composition of the fuel supplied to the analyzed system

Fuel Component	Molar fraction x_0, x_1 kmol/kmol
Nitrogen	0.014
Methane	0.954
Ethane	0.032

Table 24 The composition of the regasified LNG

LNG Component	Molar fraction x_0, x_1 kmol/kmol
Methane	1.000

Table 25 The exhaust gases composition for the analyzed system

Flue gas component	Molar fraction $x=x_0$ kmol/kmol	Molar fraction $x=x_1$ kmol/kmol
Oxygen	0.135	0.1343
Carbon Dioxide	0.0297	0.0299
Water	0.1052	0.1067
Nitrogen	0.7214	0.7205
Argon	0.0087	0.0087

Tables attached in Appendix B2 present data on thermodynamic parameters of streams constituting the analysed cycle for its reference and operational states. Pressure, temperature as well as mass and energy balances were obtained by conducting simulations in the Thermoflex 26 [1] program, after which the results were implemented in the Excel program with CoolProp [2] and Refprop [3] add-ins, which were used to calculate the value of specific enthalpy, entropy and exergy. The specified exergy flows were calculated on the basis of the equations contained in chapter 3.

In turn, table placed in Appendix B3 presents the values of exergy flows for both operational states. Exergy flows were obtained by multiplying mass flow and specific physical exergy for all streams but fuel. For fuel streams j= {2,3}, in addition to physical exergy, chemical exergy was added. Specific chemical exergy was calculated according to formula (10) and multiplied by mass flow. x_0 represents reference state while x_1 stands for operational state.

The separation of two operational states required the assumption of a constant output net power in each of them, therefore it was assumed that the obtained net power crossing system boundary of the CCGT cycle should be equal to 67 984 kW in both working states.

Referring to Table 10, it can be concluded at the outset that the operation of the system under analysis as a result of the introduced changes has deteriorated, because its exergy efficiency has been reduced. As can be seen with the determined net output power from the system, a larger fuel stream should be delivered to the system in the operational state in relation to the reference one, which translates to a greater value of the exergy flow. In addition, taking into account the condenser, it can be seen that a larger stream of heat exergy goes to the environment (sea water) in the operational state compared to the reference one, so the external loss due to dissipation is greater in the operational state. At the same time, it should be noted that the feed water pump as a result of changes such as the reduction of the isentropic efficiency of this pump, in the operational state increased its demand for electricity. Electricity consumption of other pumps rises just a bit which is a result of flow increase.

6.3. Thermoeconomic calculations

The calculations were carried out analogously to those of a simple CCGT power plant, which was discussed in detail in previous chapters. However, calculations for some components resulted in obtaining unexpected values. Calculations have been checked extensively and still, not-physical results (negative exergy or efficiency over 100%) appeared.

At this point, due to special behaviour of exergy as described in 6.4 and due to appearance of fluids of below ambient temperature a modification to the method of exergy calculation described in 3.3 had to be done.

The method used for the decomposition of the physical exergy described in chapter (7) is based on [20]. However, author of mentioned work points out that when for analysed cycle only increases of enthalpy, entropy or exergy appear, calculation of reference enthalpy i_0 and reference entropy s_0 can be done for any reference point. It is best to assume such reference parameters, not to get negative exergy values.

In particular, the change of reference point needs to be applied for pressure exergy. Usually reference temperature for pressure part of exergy is assumed as T_0 (ambient temperature). That is done because ambient temperature is usually the lowest temperature in the system. However, in the case analysed in this dissertation, the lowest temperature in the system is the LNG temperature entering the system. Its temperature is equal to -162 °C, which is much lower than ambient temperature. As a result, when considering a T_0 value higher than the lowest system temperature, it may happen that the property point (T_0, p) is in the gas phase, while (T, p) corresponds to a liquid state. If the point (T_0, p) is in the gas phase, its pressure exergy will be greater than if it were in the liquid phase, since the work available in such process depends on the volume (note that the distance between isothermal lines in a T-s diagram is greater in the gas phase than in the liquid phase) [21].

Mathematical representation of the described adjustment is as follows:

$$\mathrm{b_{f\_T}} = [\mathrm{i}(\mathrm{T},\mathrm{p}) - \mathrm{i}(T_0, p)] - \mathrm{T_0}[\mathrm{s}(\mathrm{T},\mathrm{p}) - s(T_0, p)] \tag{84}$$

where:
$\mathrm{b_{f\_T}}$ – temperature part of specific physical exergy,
i – specific physical enthalpy determined for given parameters,
s – specific physical entropy determined for given parameters,
T – temperature of the fluid,
p – pressure of the fluid,
$\mathrm{T_0}$ – ambient temperature.

$$\mathrm{b_{f\_p}} = \left[\mathrm{i}\left(T_{ref}, \mathrm{p}\right) - \mathrm{i}\left(T_{ref}, p_0\right)\right] - \mathrm{T_0}\left[\mathrm{s}\left(T_{ref}, \mathrm{p}\right) - s\left(T_{ref}, p_0\right)\right] \tag{85}$$

where:
$\mathrm{b_{f\_p}}$ – pressure part of specific physical exergy,
i – specific physical enthalpy determined for given parameters,
s – specific physical entropy determined for given parameters,
T_{ref} – reference temperature – lowest temperature in the system/subsystem (note that may be different for different fluids: -162 °C for LNG and -51.03°C for ammonia),
p – pressure of the fluid,
$\mathrm{p_0}$ – reference pressure,
$\mathrm{T_0}$ – ambient temperature.

Due to the extensive record of some matrices constituting an indispensable part of the calculations, it was impossible to place them in this work. Steps for carrying out the calculations are the same as for simple CCGT cycle.

Results of Exergy Analysis and Exergy Cost Analysis for CCGT plant integrated with LNG regasification are presented in appendices B4, B5, B6, B7, B8, B9.

Appendix B4 presents column vectors of F_B fuels, P_B products as well as I_B irreversibility for the analysed CCGT cycle integrated with LNG regasification for both the reference state x_0 and the operational state x_1. Analysing the results presented in appendix B4 it can be concluded that the biggest exergy losses so the greatest irreversibility of the thermodynamic process, appear at second component – gas turbine. It results from the fact that combustion occurs in it as a very irreversible process. In addition, the full set of elements constituting to gas turbine in the analysis are treated as one component - it is not distributed between the compressor, combustion chamber and turbine, hence the obtained irreversibility is the sum of the imperfections of each of these devices. Moreover, the same behaviour was observed for simple CCGT plant.

Exergy efficiency and specific exergy consumption values for components of CCGT plant integrated with LNG regasification are presented in appendix B5. Analysing values from appendix B5, it can be noticed that the smallest exergy efficiency, and hence the largest specific consumption of exergy, has the component number 16 – condensate pump. This is the same case as in simple CCGT plant. However absolute exergy loss of that pump is not significant. Reason for small exergy efficiency of that pump was described in chapter 5.3. Other components characterised by small exergy efficiency are steam turbine condenser (cooled with ammonia), LNG pump, LNG-sea water heat exchangers or ammonia pump. Those are all components where fluids of temperature below ambient are involved and heat transfer is occurring between fluids of high temperature difference. Explanation why heating of fluids which have below-ambient which connected with great loss of energy potential (work) is described in chapter 6.4.

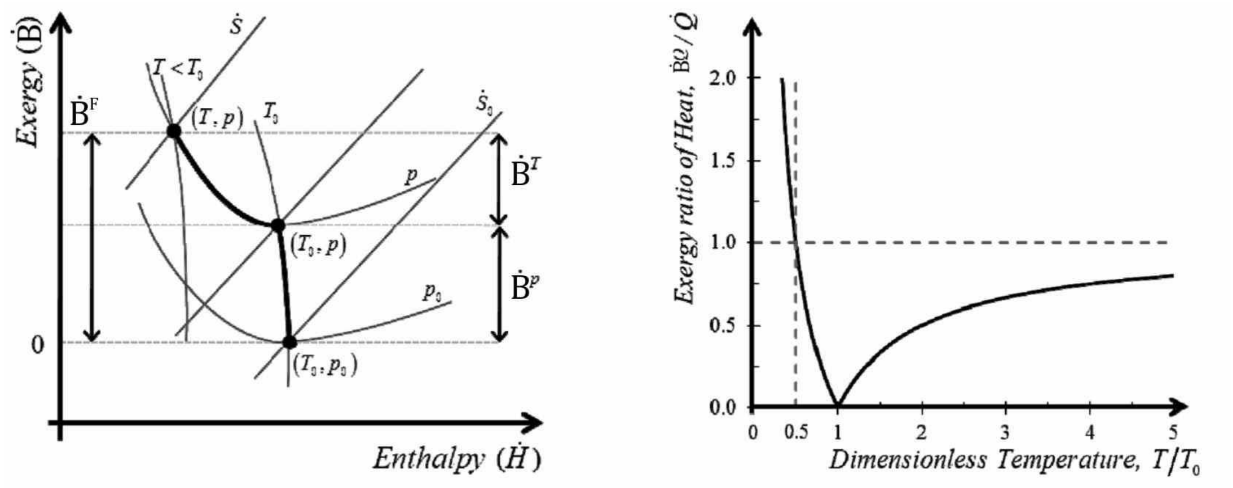
Analysing appendices B6 and B7, it can be noticed that exergy costs both in the reference and operational states increase as the process progresses, so the farther in the chain of irreversible changes the stream has a higher unit exergy cost.

Results of calculations presented in appendices B8, B9 act as a way for checking the correctness of calculations as they present the exergy cost for each component calculated using two methods. Those results are then used for exergy diagnosis.

As in the case of simple CCGT plant, after carrying out Exergy Cost Calculation, next step was Exergy Diagnosis. Due to the fact that the matrix method as described in [22] has not been tested before for such a specific case (power plant integrated with LNG regasification) due to doubtful results further calculations although completed are not presented. It is not said that the method itself is wrong, but it may require some adjustments for such a special case. Possible explanations and suggestions for improving the method are presented in chapters 6.4 and 8.1.

6.4. Remarks for exergy analyses of LNG systems by matrix method

Figure 20 (a) presents the visual representation of the physical exergy ($\dot{\mathrm{B}}_F$) and its components in an Exergy–Enthalpy diagram. Division between temperature ($\dot{\mathrm{B}}_T$) and pressure ($\dot{\mathrm{B}}_p$) part of exergy is done to show the exergy contributions when the main exergy transformation occurs between $\dot{\mathrm{B}}_T$, $\dot{\mathrm{B}}_p$ and shaft work, for working conditions below ambient temperature. The amount of exergy of a flow or heat source depends on the temperature. Transformations of the temperature part of exergy for a substance stream $\dot{\mathrm{B}}_T$ is represented by the isobars in Figure 20 (a). These isobars without doubt prove that the exergy requirement under ambient temperature is higher than above ambient temperature for the same change in temperature (increment above T_0 and decrement below T_0). The exergy accompanying heat depends on temperature.



(a) (b)

Figure 20 (a) Temperature-based and pressure-based exergy and (b) exergy content of heat vs. temperature [23]

What is more from Figure 20 (b) one can deduct that the exergy of heat (energy flow) is horizontally asymptotic to $\dot{Q}$ above T_0 which means that the maximum work produced even by a reversible heat engine will always be less than the energy supplied by the heat source ($\dot{Q}$). Below T_0, the exergy of heat is vertically asymptotic to infinite when the temperature approaches 0 K which means that the minimum work required to take $\dot{Q}$ from T_0 to a lower temperature can be larger than $\dot{Q}$. It must be noticed that over ambient temperature, heat is always less worth (has lower exergy) than work, while for temperatures below half of T_0, the ratio between $\dot{\mathrm{B}}_Q$ and $\dot{Q}$ is larger than one, thus heat (cold thermal energy) is more valuable than work. This special behaviour can be expressed by equation (86) [11].

$$\frac{\dot{\mathrm{B}}_Q}{\dot{Q}} = \left|\frac{T - T_0}{T}\right| \tag{86}$$

where:
$\dot{\mathrm{B}}_Q$ – exergy flow,
$\dot{Q}$ – energy flow,
T – stream temperature,
T_0 – ambient temperature.

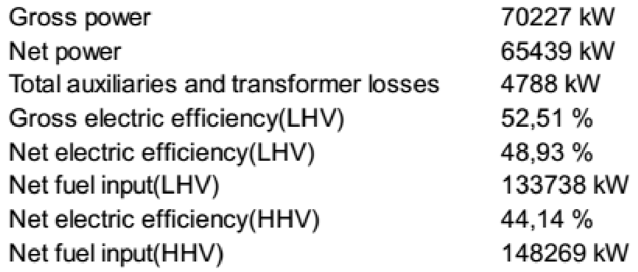
Due to the behaviour explained above sources and the sinks are not always the same for energy and exergy flows. One can conclude that for heat exchangers operating below ambient temperature, the exergy source is the cold stream and the exergy sink is the hot stream. In most cases for heat exchangers, a decrement of the exergy of a given stream represents an exergy source while an increment of exergy represents an exergy sink However the above considerations does not take into account pressure drops, thus pressure part of exergy. Pressure loss (exergy destruction) caused by friction results in heating the fluid which translates to available exergy increment in the exergy sources and the capacity reduction of the exergy sinks [23].

Matrix method for exergy cost calculation as described in chapter 5.3 requires unambiguous and binary ("-1" or "1") sinks and sources (fuel and product) definition. As demonstrated in the above considerations sinks and sources, thus fuel and product can be shifting their roles for processes and streams crossing ambient temperature. Method presented in chapter 5.3 does not allow to attribute single exergy flow to be partly fuel and partly product. Matrix method still remains a great tool for diagnosis of very complex systems. However, its utilization for cases like the CCGT plant integrated with LNG regasification being the subject of this dissertation requires method improvement.

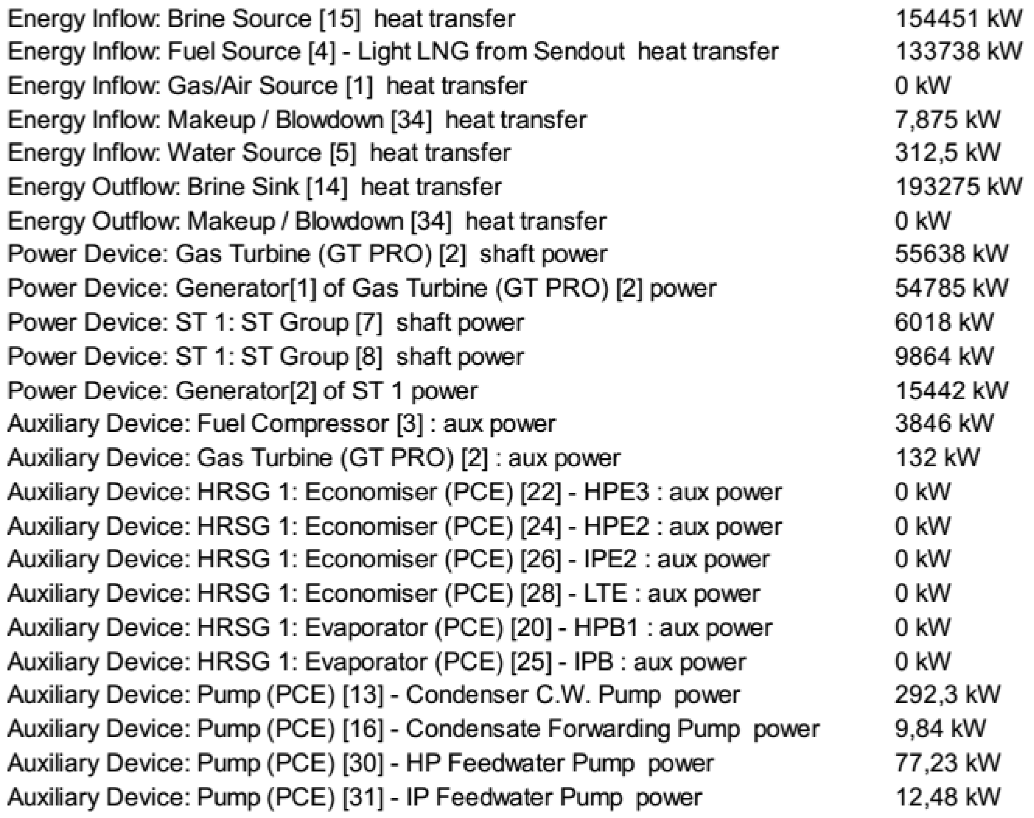
7. Comparison of performance of standard CCGT plant with CCGT plant integrated with LNG regasification

Due to the method limitations described in chapter 6.4 it was not possible to compare between two plants after running full exergy diagnosis. However, two plants and thus results on integrating LNG regasification can be assessed on the basis of energy analysis.

Below are presented main performance parameters of two plants in their reference state of operation. Parameters are results of calculations obtained with Thermoflex 26 [1] software.

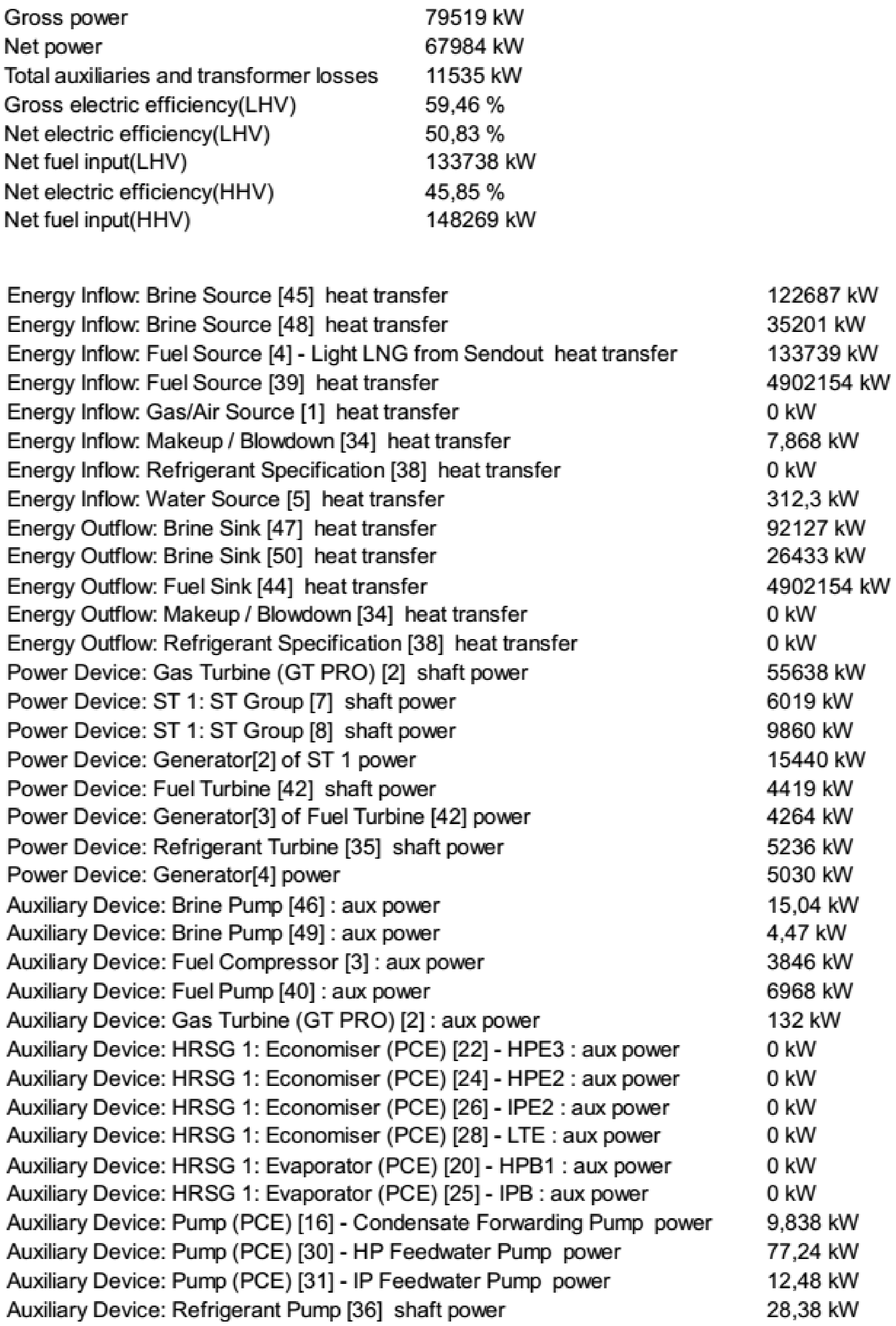


Gross power	70227 kW
Net power	65439 kW
Total auxiliaries and transformer losses	4788 kW
Gross electric efficiency(LHV)	52,51 %
Net electric efficiency(LHV)	48,93 %
Net fuel input(LHV)	133738 kW
Net electric efficiency(HHV)	44,14 %
Net fuel input(HHV)	148269 kW



Energy Inflow: Brine Source [15] heat transfer	154451 kW
Energy Inflow: Fuel Source [4] - Light LNG from Sendout heat transfer	133738 kW
Energy Inflow: Gas/Air Source [1] heat transfer	0 kW
Energy Inflow: Makeup / Blowdown [34] heat transfer	7,875 kW
Energy Inflow: Water Source [5] heat transfer	312,5 kW
Energy Outflow: Brine Sink [14] heat transfer	193275 kW
Energy Outflow: Makeup / Blowdown [34] heat transfer	0 kW
Power Device: Gas Turbine (GT PRO) [2] shaft power	55638 kW
Power Device: Generator[1] of Gas Turbine (GT PRO) [2] power	54785 kW
Power Device: ST 1: ST Group [7] shaft power	6018 kW
Power Device: ST 1: ST Group [8] shaft power	9864 kW
Power Device: Generator[2] of ST 1 power	15442 kW
Auxiliary Device: Fuel Compressor [3] : aux power	3846 kW
Auxiliary Device: Gas Turbine (GT PRO) [2] : aux power	132 kW
Auxiliary Device: HRSG 1: Economiser (PCE) [22] - HPE3 : aux power	0 kW
Auxiliary Device: HRSG 1: Economiser (PCE) [24] - HPE2 : aux power	0 kW
Auxiliary Device: HRSG 1: Economiser (PCE) [26] - IPE2 : aux power	0 kW
Auxiliary Device: HRSG 1: Economiser (PCE) [28] - LTE : aux power	0 kW
Auxiliary Device: HRSG 1: Evaporator (PCE) [20] - HPB1 : aux power	0 kW
Auxiliary Device: HRSG 1: Evaporator (PCE) [25] - IPB : aux power	0 kW
Auxiliary Device: Pump (PCE) [13] - Condenser C.W. Pump power	292,3 kW
Auxiliary Device: Pump (PCE) [16] - Condensate Forwarding Pump power	9,84 kW
Auxiliary Device: Pump (PCE) [30] - HP Feedwater Pump power	77,23 kW
Auxiliary Device: Pump (PCE) [31] - IP Feedwater Pump power	12,48 kW

Figure 21 Performance of CCGT system



Gross power	79519 kW
Net power	67984 kW
Total auxiliaries and transformer losses	11535 kW
Gross electric efficiency(LHV)	59,46 %
Net electric efficiency(LHV)	50,83 %
Net fuel input(LHV)	133738 kW
Net electric efficiency(HHV)	45,85 %
Net fuel input(HHV)	148269 kW

Energy Inflow: Brine Source [45] heat transfer	122687 kW
Energy Inflow: Brine Source [48] heat transfer	35201 kW
Energy Inflow: Fuel Source [4] - Light LNG from Sendout heat transfer	133739 kW
Energy Inflow: Fuel Source [39] heat transfer	4902154 kW
Energy Inflow: Gas/Air Source [1] heat transfer	0 kW
Energy Inflow: Makeup / Blowdown [34] heat transfer	7,868 kW
Energy Inflow: Refrigerant Specification [38] heat transfer	0 kW
Energy Inflow: Water Source [5] heat transfer	312,3 kW
Energy Outflow: Brine Sink [47] heat transfer	92127 kW
Energy Outflow: Brine Sink [50] heat transfer	26433 kW
Energy Outflow: Fuel Sink [44] heat transfer	4902154 kW
Energy Outflow: Makeup / Blowdown [34] heat transfer	0 kW
Energy Outflow: Refrigerant Specification [38] heat transfer	0 kW
Power Device: Gas Turbine (GT PRO) [2] shaft power	55638 kW
Power Device: ST 1: ST Group [7] shaft power	6019 kW
Power Device: ST 1: ST Group [8] shaft power	9860 kW
Power Device: Generator[2] of ST 1 power	15440 kW
Power Device: Fuel Turbine [42] shaft power	4419 kW
Power Device: Generator[3] of Fuel Turbine [42] power	4264 kW
Power Device: Refrigerant Turbine [35] shaft power	5236 kW
Power Device: Generator[4] power	5030 kW
Auxiliary Device: Brine Pump [46] : aux power	15,04 kW
Auxiliary Device: Brine Pump [49] : aux power	4,47 kW
Auxiliary Device: Fuel Compressor [3] : aux power	3846 kW
Auxiliary Device: Fuel Pump [40] : aux power	6968 kW
Auxiliary Device: Gas Turbine (GT PRO) [2] : aux power	132 kW
Auxiliary Device: HRSG 1: Economiser (PCE) [22] - HPE3 : aux power	0 kW
Auxiliary Device: HRSG 1: Economiser (PCE) [24] - HPE2 : aux power	0 kW
Auxiliary Device: HRSG 1: Economiser (PCE) [26] - IPE2 : aux power	0 kW
Auxiliary Device: HRSG 1: Economiser (PCE) [28] - LTE : aux power	0 kW
Auxiliary Device: HRSG 1: Evaporator (PCE) [20] - HPB1 : aux power	0 kW
Auxiliary Device: HRSG 1: Evaporator (PCE) [25] - IPB : aux power	0 kW
Auxiliary Device: Pump (PCE) [16] - Condensate Forwarding Pump power	9,838 kW
Auxiliary Device: Pump (PCE) [30] - HP Feedwater Pump power	77,24 kW
Auxiliary Device: Pump (PCE) [31] - IP Feedwater Pump power	12,48 kW
Auxiliary Device: Refrigerant Pump [36] shaft power	28,38 kW

Figure 22 Performance of CCGT integrated with LNG regasyfication system

Net electric efficiency of CCGT plant equal to 44.14% is far from state of the art CCGT plants (efficiency over 50%). This is due to application of industrial gas turbine of lower class than modern CCGT plants. However, employed gas turbine is suitable for available stream of LNG and gas supply and offers long life with long annual working time. Efficiency is strictly connected with temperatures in the system (first of all in gas turbine and steam turbine cycle). Modern CCGT systems operate in temperatures higher than for the plant presented thanks to better heat and creep resistant materials.

Plant integrated with LNG regasification was created by adding ammonia and LNG cycle to the simple CCGT plant. Both plants are characterized by similar fuel gas input 133 738 kW (LHV) and 136490 kW (LHV). However, plant integrated with LNG regasification has net electricity production of 67 984 kW compared to 65 439 kW of simple plant resulting in differences in energy efficiency. Additional ammonia and LNG turbines provides over than 9 MW of electric power but part of this surplus needs to be utilized to drive additional equipment (mainly pumps), thus obtaining just around extra 2 MW. Whole this power is created due to exergy recovery from LNG regasification. Extra energy might have been created in steam turbine due to additional cooling of steam condenser but in that case, plant was set to have same condenser pressure, thus temperature for both simple and complex plant. The difference is that in simple cycle heat from the condenser is lost to the environment while in the second plant is utilized for LNG regasification. Analysed cycles have different energy efficiency which net value is 48.93% for standard CCGT plant and 50.83% for plant integrated with LNG regasification.

Differences discussed above are not that great. 1.9% efficiency improvement might be considered a good result but considering possible investment costs might not be that attractive. What is the main advantage of proposed cycle being additional to providing extra electricity is the fact that the plant regasifies LNG and provides a natural gas with just right pressure (8.4 MPa) and temperature (1°C) to a gas transmission network. Otherwise LNG will have to be regasified and compressed by conventional method which is connected with high energy costs. To illustrate the difference, using Submerged Combustion Vaporisers would involve of losing 1,5% of LNG stream just for generating heat to evaporate LNG. What is more for the same mass stream as assumed in the analysed plant (~98 kg/s) LNG pumps would require about 4 MWe to achieve pressure required by gas transmission network.

8. Summary and conclusions

As part of this work, the focus was on the method of transporting natural gas in liquefied form (LNG). The LNG production and supply chain as well as the current state of the global market for this fuel were described. The methods of regasification of LNG and the possibility of recovery of cryogenic exergy stored in it have been reviewed. The concept of exergy and exergy cost analysis has been described.

The main element of the work was the implementation of mathematic models of two Combined Cycle Gas Turbine systems in proper software and then their thermoeconomic analysis, with the difference that one of them was integrated with LNG regasification.

As part of the conducted diagnosis so-called matrix method has been presented. This method allows the analysis of even very complicated systems, such as the presented CCGT power plant. The first stage of the calculations was to model the system in the Thermoflex 26 [1] software, where two operating states were created - reference x_0 and operating x_1. The first of the states was characterized by the highest perfection of processes going in the system, while the second resulted from the deterioration of the working conditions of selected components. After the simulation, a full set of parameters for each stream was obtained, which in turn allowed to determine the value of exergy at these points - after importing simulation results into Microsoft Excel linked to Cool Prop [2] and REFPROP [3] databases. Finally, after obtaining the exergy value at each of the points in the system, a matrix analysis was carried out using the Microsoft Excel calculation sheet. All following stages of thermoeconomic analysis were shown on the example of a simple CCGT plant, explaining all the mathematical operations.

Algorithm for calculations of CCGT plant integrated with LNG regasification should have been theoretically identical as for simple CCGT plant. However, obtained results were very doubtful. Calculations have been checked extensively and it was concluded that the proposed method is not adjusted for such a specific case. The case of CCGT plant integrated with LNG regasification was found to be unique due to the fact that for some system components thermodynamic processes have been crossing ambient temperature. Due to special behaviour of exergy in temperatures below ambient, it is usually very hard to define so called (in matrix method) fuel and product. In such a specific case fuel and product may be shifting between themselves but not completely. They may shift just in part which could not have been implemented in matrix method which requires unambiguous and binary definition of fuels and products. However, it only prevented carrying out of exergy diagnosis, but exergy and exergy cost analyses have been conducted successfully.

Analysing the results obtained for simple CCGT plant was observed that the lowest exergy efficiency, and consequently the highest specific exergy cost is bounded to component number 16 – condensate pump. However, it is worth noticing that absolute exergy loss of that component is not a significant part of all exergy losses compared to components like gas turbine, fuel compressor or steam turbine. The reason for small exergy efficiency of condensate pump is its low adiabatic efficiency equal to 14.57%. High exergy cost gas turbine, fuel compressor and steam turbine are due to irreversibility of ongoing thermodynamic processes.

On the other hand, for simple CCGT plant, the smallest specific exergy cost, close to one, is characterized by flow splitters, a mixer, pipelines and flue gas duct from Gas Turbine to HRSG. In the case of splitters, the exergy cost is equal to one due to the fact that there is no exergy loss - streams are only divided, but their parameters do not change. In the case of a mixer, its low-cost results from the mixing of two streams with similar thermodynamic parameters. In turn, the exergy cost of pipes and flue gas duct from Gas Turbine to HRSG is close to one, since relatively small pressure losses translate into insignificant losses of exergy.

Analysing the results obtained for the simple CCGT plant and Figure 16, it can be seen that as a result of the introduced changes in the system, the value of exergy of fuel delivered to the cycle increased while exergy of useful products (net electricity) was kept the same. The component that is characterized by the highest increase in fuel consumption in both reference and operational state is the gas turbine. It can also be concluded that several components have reduced the value of fuel exergy, an example of which are components such as 18 and 19 (heat exchangers of HRSG) and generator number 2. There is no change in exergy delivered to steam turbine (i=7, 8) as steam parameters entering the turbine parts was set rigidly.

Conducting thermoeconomic analysis is a convenient and transparent way to diagnose the chosen system. It can be stated how the deterioration of the operation of one component affects the operation of the entire system, and in particular what are the consequences of this in relation to the operation of other devices identified in the analysed cycle. In addition, this analysis may serve as an excellent optimization tool, as it is possible, as in the present case, to distinguish several operating states characterized by changed parameters, and then to check which one works in the most effective way, and therefore where the losses of exergy are the smallest and where it is observed the lowest consumption of fuel exergy. In addition, this analysis is particularly important in the era of care for the environment and exhaustible natural resources. However, one should be especially careful if the chosen method for thermoeconomic analysis works properly for any cycle and for any temperature range.

By comparing the simple CCGT plant with the CCGT plant integrated with LNG regasification by the means of energy performance it was shown that energy efficiency of the cycle can be increased by 1.9% while decreasing LNG consumption for regasification in SCV regasifiers by 1.5%. What is more energy recovered from LNG allows to drive LNG pumps providing energy that would otherwise have to be supplied from outside. Such a solution leads to a reduction in energy consumption as well as emissions reduction. However, any improvement to energy systems should have not only be justified by thermodynamics but economy as well.

8.1. Further Work Recommendation

Matrix method as described in [22] cannot be used without additional method development for unique cases as showed in chapter 6.4. Method improvement might be a great topic for a doctoral dissertation.

Beside improving the basis of the matrix method, it is worth consideration to automate part of calculations, together with matrices generation which will save time of future users.

Main disadvantage of method improvement will be most probably the fact the utilizing Excel software for calculations will be limited. Excel spreadsheets does not allow to change part of the matrices which are subjects to operations on matrices which might be required to correctly conduct the analysis. Possible solution to stay with Excel software will be utilisation of Visual Basic programming language.

Bibliography

[1] Thermoflow Inc, Thermoflex 26 (Version 26.1.1) [Computer software], Jacksonville, FL, 2017.

[2] Bell I. H., Wronski J., Quoilin S., Lemort V., *Pure and Pseudo-pure Fluid Thermophysical Property Evaluation and the Open-Source Thermophysical Property Library CoolProp*, Industrial & Engineering Chemistry Research 2014.

[3] Lemmon E.W., Huber M.L., McLinden M.O., *NIST Standard Reference Database 23: Reference Fluid Thermodynamic and Transport Properties-REFPROP, Version 9.1*, National Institute of Standards and Technology, Standard Reference Data Program, Gaithersburg, 2013.

[4] Mokhatab S., Mak J., Valappil J., Wood D., *Handbook of Liquefied Natural Gas*, Gulf Professional Publishing, Houston, 2013.

[5] Finn A.J., Johnson G.L., Tomlinson T.R., *LNG Technology for Offshore and Mid-scale Plants*, 9th Annual GPA Convention, Atlanta, GA, 2000.

[6] Jamieson D., Johnson P., Redding P., *Targeting and Achieving Lower Cost Liquefaction Plants*, 12th International Conference and Exhibition on Liquefied Natural Gas, Perth, 1998.

[7] International Gas Union, *2017 World LNG report*, Oslo, 2017.

[8] Sharrat C., *LNG terminal cold energy integration opportunities offered by contractors*, LNG Journal, 2012.

[9] Romero G. M., Ferreiro G. R., Romero G. J., Carbia C. J., *Review of thermal cycles exploiting the exergy of liquefied natural gas in the regasification process*, Renewable and Sustainable Energy Reviews 38, 2014.

[10] Dincer I., Cengel Y.A., *Energy, entropy, and exergy concepts and their roles in thermal engineering*, Entropy*, 3*, 116-149, 2001.

[11] Szargut J., *TERMODYNAMIKA TECHNICZNA*, Wydawnictwo Naukowe PWN, Warszawa, 1991.

[12] Szargut J., *EGZERGIA Poradnik obliczania i stosowania*, Wydawnictwo Politechniki Śląskiej, Gliwice 2007.

[13] Valero A., Lozano M. A., Munoz M., *A general theory of exergy saving*, Computer-Aided Engineering of Energy Systems. 2. 1-21, 1986.

[14] Stanek W., *Thermo-Economic Analysis Lecture 6*, Institute of thermal technology, Gliwice 2016.

[15] Stanek W., *Thermo-Economic Analysis Lecture 8*, Institute of thermal technology, Gliwice 2016.

[16] Lozano M. A., Valero A., *THEORY OF THE EXERGETIC COST*, Departamento de Ingenieria Mecanica, Universidad de Zaragoza, Spain, 1993.

[17] Stanek W.,*Thermo-Economic Analysis Lecture 5*, Institute of thermal technology, Gliwice 2016.

[18] Lozano M. A., Bartolome J. L., Valero A., Reini M., *Thermoeconomic diagnosis of energy systems*, Proceedings of the Third Florence World Energy Research Symposium, 149-156, 1994.

[19] Valero A., *The thermodynamic process of cost formation*, Mechanical Engineering, Energy Systems and Sustainable Development - Volume IV, United Kingdom, 2009.

[20] Szargut J., Petela R., *Egzergia*, WNT, Warszawa, 1965.

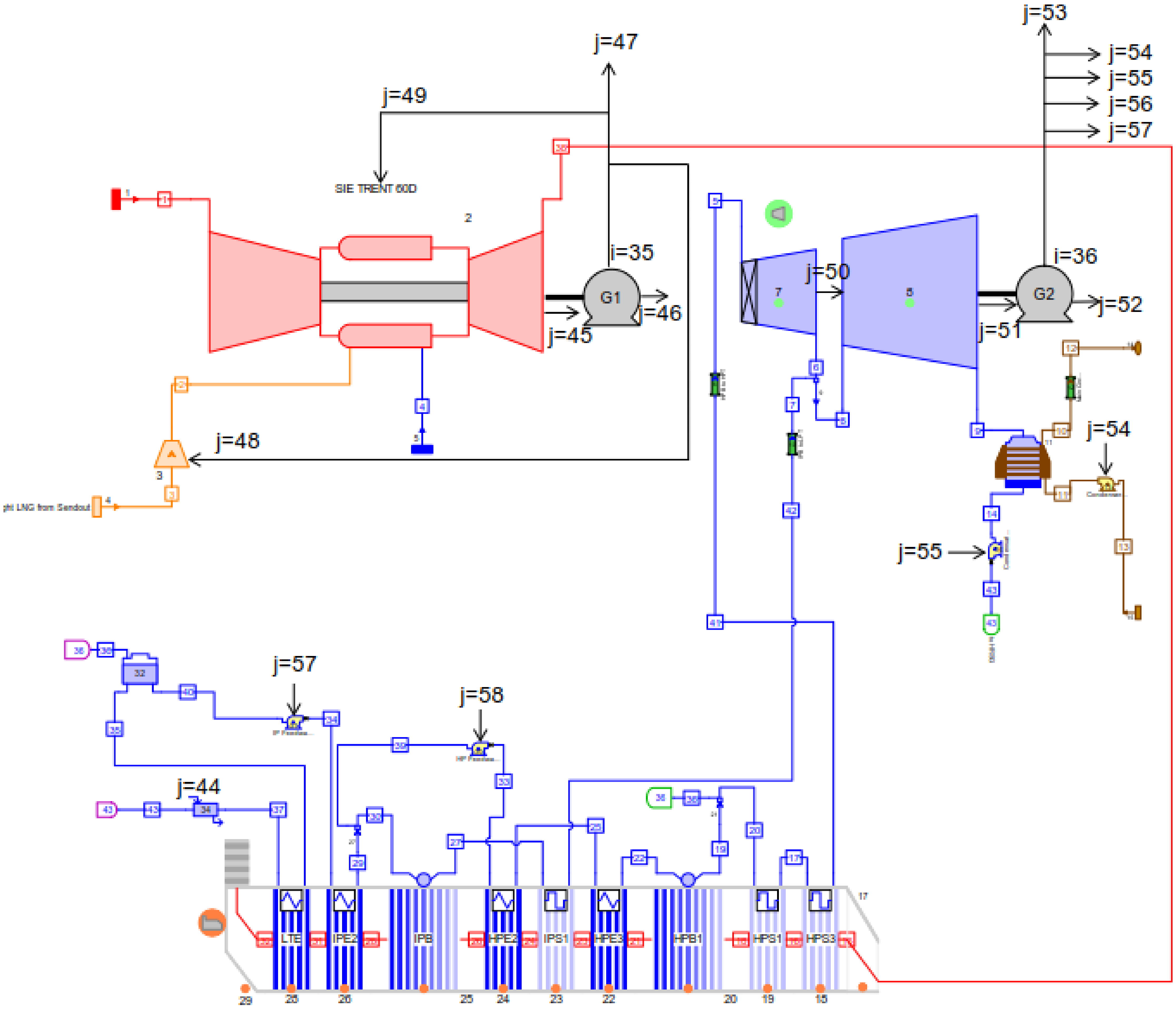
[21] Ferreira P.A., *Proposta e Avaliação Termodinâmica de Soluções para o Aproveitamento da Exergia na Regaseificação de GNL*, Universidade Nova de Lisboa, [Master Dissertation], 2015.

[22] Stanek W., *Analiza egzergetyczna w teorii i praktyce,* Gliwice, 2016.

[23] Marmolejo-Correa, D., Gundersen, T., *A new efficiency parameter for exergy analysis in low temperature processes*. Int. J. Exergy, Vol. 17, 2015.

APPENDICES

A
Combined Cycle Gas Turbine system with all exergy flows defined



A1
Incidence matrix A

		Matrix A																																																						
		Stream j																																																						
i	Component	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
2	Gas Turbine	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	-1	0	0	0	1	0	0	0	0	0	0	0	0
3	Fuel Compressor	0	-1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
6	Pipe	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	ST 1: ST Group	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0
8	ST 1: ST Group	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0
9	Mixer	0	0	0	0	0	1	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	Pipe	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Water-cooled Condenser	0	0	0	0	0	0	0	0	1	-1	1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Pipe	0	0	0	0	0	0	0	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	Pump	0	0	0	0	0	0	0	0	0	0	-1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
16	Pump	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
17	HRSG 1: Duct - GT to Horizontal HRSG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	HRSG 1: Superheater	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	HRSG 1: Superheater	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	-1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	HRSG 1: Evaporator	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	-1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	Splitter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	HRSG 1: Economiser	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	-1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	HRSG 1: Superheater	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	HRSG 1: Economiser	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	-1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	HRSG 1: Evaporator	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	-1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	HRSG 1: Economiser	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	-1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	Splitter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	HRSG 1: Economiser	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	-1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	Pump	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
31	Pump	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
32	Deaerator	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	Makeup / Blowdown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
35	Generator 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	-1	-1	0	0	0	0	0	0	0	0
36	Generator 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	-1	-1	-1	-1	-1

A2

Fuels matrix A_F

		Matrix AF																																																								
		Stream j																																																								
i	**Component**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
2	**Gas Turbine**	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
3	**Fuel Compressor**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
6	**Pipe**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	**ST 1: ST Group**	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	**ST 1: ST Group**	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	**Mixer**	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	**Pipe**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	**Water-cooled Condenser**	0	0	0	0	0	0	0	0	1	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	**Pipe**	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	**Pump**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
16	**Pump**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
17	**HRSG 1: Duct - GT to Horizontal HRSG**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	**HRSG 1: Superheater**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	**HRSG 1: Superheater**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	**HRSG 1: Evaporator**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	**Splitter**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	**HRSG 1: Economiser**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	**HRSG 1: Superheater**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	**HRSG 1: Economiser**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	**HRSG 1: Evaporator**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	**HRSG 1: Economiser**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	**Splitter**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	**HRSG 1: Economiser**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	**Pump**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
31	**Pump**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
32	**Deaerator**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	**Makeup / Blowdown**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
35	**Generator 1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
36	**Generator 2**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0

A3

Products matrix A_P

		Matrix AP																																																						
		Stream j																																																						
i	Component	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
2	Gas Turbine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
3	Fuel Compressor	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Pipe	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	ST 1: ST Group	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
8	ST 1: ST Group	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
9	Mixer	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	Pipe	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Water-cooled Condenser	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Pipe	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	Pump	0	0	0	0	0	0	0	0	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	Pump	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	HRSG 1: Duct - GT to Horizontal HRSG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	HRSG 1: Superheater	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	HRSG 1: Superheater	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	HRSG 1: Evaporator	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	Splitter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	HRSG 1: Economiser	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	HRSG 1: Superheater	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	HRSG 1: Economiser	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	HRSG 1: Evaporator	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	HRSG 1: Economiser	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	Splitter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	HRSG 1: Economiser	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	Pump	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	Pump	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	Deaerator	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	Makeup / Blowdown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	Generator 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
36	Generator 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1

A4

Matrix $\mathbf{A_k}$ of the coefficients of the exergy cost balance equations for reference state x_0

i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	Y*
2	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	-1	0	0	0	1	0	0	0	0	0	0	0	0	0
3	0	-1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0
9	0	0	0	0	0	1	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	1	-1	1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	-1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	-1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	-1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	-1.027	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	-1.033	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	-1.310	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	-1.023	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	-1.003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	-1.027	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	-1.045	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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8	0	0	0	0	0	0	0	1.000	-3.976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-50807.000	1.000	0	0	0	0	0	0	0	0	0	0	0
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35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	-384.902	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-15050.150	1.000	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	-51.489	0	0	0	0
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36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	-194.874	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	-1205.942	0

Matrix $\mathbf{A_k}$ of the coefficients of the exergy cost balance equations for operational state x_1

i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	Y*
2	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	-1	0	0	0	1	0	0	0	0	0	0	0	0	0
3	0	-1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1.044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	1	-1.622	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1	-3.674	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	1	0	0	0	0	-33.099	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-51987.000	1	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-12.717	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-393.841	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-14240.843	1	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-43.590	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1430.234	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-180.630	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	-1124.869	0

A5

Matrix $(\mathbf{A}_k)^{-1}$ for reference state x_0

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	-0.034	-1.034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.073	0	1.034	0.034	0.034	0	0	0.039	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.073	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	-0.197	-0.197	-1.009	-0.006	-0.006	-0.010	-0.010	0	0	0	-0.738	-0.358	-1.009	-1.009	-1.002	-1.002	-1.002	-0.010	-1.002	-0.010	-0.738	-0.738	-0.738	-1.002	-0.738	-0.738	-0.738	-0.014	-0.006	0.197	0.197	0.197	0.738	0	-0.183	0.650	0.668	0.683	0.895	-0.076	0.916	-0.036	0.687	0.706	-0.728	-0.264	-0.002	-0.004	-0.022	0	-0.014	0	0	0	0	-0.005	-0.001
6	-0.120	-0.120	-0.613	-0.004	-0.004	-0.006	-0.006	0	0	0	-0.448	-0.218	-0.613	-0.613	-0.609	-0.609	-0.609	-0.006	-0.609	-0.006	-0.448	-0.448	-0.448	-0.609	-0.448	-0.448	-0.448	-0.009	-0.004	0.120	0.120	0.120	0.448	0	-0.111	0.395	0.406	0.415	0.544	-0.046	0.557	-0.022	0.418	0.429	-0.442	-0.161	-0.609	-0.002	-0.013	0	-0.008	0	0	0	0	-0.003	0
7	-0.049	-0.049	-0.002	0	0	-0.002	-1.002	0	0	0	-0.273	-0.089	-0.002	-0.002	-0.008	-0.008	-0.008	-1.002	-0.008	-1.002	-0.273	-0.273	-0.273	-0.008	-0.273	-0.273	-0.273	-0.004	0	0.049	0.049	0.049	0.273	0	-0.045	-0.087	-0.090	-0.086	-0.113	0.879	-0.113	0.877	0.254	0.261	0.729	0.265	-0.001	-0.002	-0.008	0	-0.003	0	0	0	0	0	0
8	-0.169	-0.169	-0.615	-0.004	-0.004	-1.008	-1.008	0	0	0	-0.721	-0.307	-0.615	-0.615	-0.617	-0.617	-0.617	-1.008	-0.617	-1.008	-0.721	-0.721	-0.721	-0.617	-0.721	-0.721	-0.721	-0.012	-0.004	0.169	0.169	0.169	0.721	0	-0.157	0.308	0.316	0.329	0.431	0.832	0.444	0.855	0.672	0.690	0.287	0.104	-0.611	-0.004	-0.021	0	-0.012	0	0	0	0	-0.003	-0.001
9	-0.042	-0.042	-0.155	-0.001	-0.001	-0.254	-0.254	0	0	0	-0.181	-0.077	-0.155	-0.155	-0.155	-0.155	-0.155	-0.254	-0.155	-0.254	-0.181	-0.181	-0.181	-0.155	-0.181	-0.181	-0.181	-0.003	-0.001	0.042	0.042	0.042	0.181	0	-0.039	0.077	0.079	0.083	0.108	0.209	0.112	0.215	0.169	0.174	0.072	0.026	-0.154	-0.253	-0.005	0	-0.003	0	0	0	0	-0.001	0
10	-0.045	-0.045	-0.166	-0.020	-0.020	-0.260	-0.260	-1.000	0	-1.000	-0.192	-0.082	-0.166	-0.166	-0.167	-0.167	-0.167	-0.260	-0.167	-0.260	-0.192	-0.192	-0.192	-0.167	-0.192	-0.192	-0.192	-0.003	-0.020	0.045	0.045	0.045	0.192	1.000	-0.042	0.084	0.087	0.090	0.118	0.214	0.121	0.220	0.179	0.183	0.069	0.025	-0.146	-0.240	0.024	0	-0.003	0	0	-0.019	0	-0.001	0
11	-0.004	-0.004	-0.016	-0.019	-0.019	-0.014	-0.014	0	0	-1.000	-0.016	-0.007	-0.016	-0.016	-0.016	-0.016	-0.016	-0.014	-0.016	-0.014	-0.016	-0.016	-0.016	-0.016	-0.016	-0.016	-0.016	0	-0.019	0.004	0.004	0.004	0.016	1.000	-0.004	0.009	0.009	0.010	0.013	0.011	0.013	0.012	0.015	0.015	-0.001	0	0.003	0.005	0	0	0	0	0	-0.019	0	0	0
12	-0.045	-0.045	-0.166	-0.020	-0.020	-0.260	-0.260	-1.000	-1.000	-1.000	-0.192	-0.082	-0.166	-0.166	-0.167	-0.167	-0.167	-0.260	-0.167	-0.260	-0.192	-0.192	-0.192	-0.167	-0.192	-0.192	-0.192	-0.003	-0.020	0.045	0.045	0.045	0.192	1.000	-0.042	0.084	0.087	0.090	0.118	0.214	0.121	0.220	0.179	0.183	0.069	0.025	-0.146	-0.240	0.024	0	-0.003	0	0	-0.019	0	-0.001	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	-0.001	-0.001	-0.005	0	0	-0.008	-0.008	0	0	0	-0.005	-0.002	-0.005	-0.005	-0.005	-0.005	-0.005	-0.008	-0.005	-0.008	-0.005	-0.005	-0.005	-0.005	-0.005	-0.005	-0.005	0	0	0.001	0.001	0.001	0.005	0	-0.001	0.002	0.002	0.002	0.003	0.006	0.003	0.006	0.005	0.005	0.002	0.001	-0.005	-0.008	-0.030	0	0	0	0	0	0	0	0
15	-0.550	-0.550	0	0	0	0	0	0	0	0	0	-1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.040	0	0.550	0.550	0.550	0	0	-0.510	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.039	-0.001	0	0	0	0	0
16	-0.536	-0.536	0	0	0	0	0	0	0	0	0	-0.974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.039	0	0.536	0.536	0.536	0	0	-0.497	-0.974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.038	-0.001	0	0	0	0	0
17	-0.183	-0.183	-0.009	-0.006	-0.006	-0.010	-0.010	0	0	0	-0.738	-0.332	-0.009	-1.009	-1.002	-1.002	-1.002	-0.010	-1.002	-0.010	-0.738	-0.738	-0.738	-1.002	-0.738	-0.738	-0.738	-0.013	-0.006	0.183	0.183	0.183	0.738	0	-0.170	0.324	0.668	0.683	0.895	-0.076	0.916	-0.036	0.687	0.706	-0.728	-0.264	-0.002	-0.004	-0.022	0	-0.013	0	0	0	0	-0.005	-0.001
18	-0.519	-0.519	0	0	0	0	0	0	0	0	0	-0.943	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.038	0	0.519	0.519	0.519	0	0	-0.481	-0.943	-0.968	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.036	-0.001	0	0	0	0	0
19	-0.170	-0.170	-0.009	-0.006	-0.006	-0.010	-0.010	0	0	0	-0.756	-0.308	-0.009	-0.009	-1.026	-0.026	-1.026	-0.010	-1.026	-0.010	-0.756	-0.756	-0.756	-1.026	-0.756	-0.756	-0.756	-0.012	-0.006	0.170	0.170	0.170	0.756	0	-0.157	-0.300	-0.308	0.700	0.917	-0.078	0.938	-0.037	0.704	0.723	-0.745	0.729	-0.002	-0.004	-0.022	0	-0.012	0	0	0	0	-0.005	-0.001
20	-0.166	-0.166	-0.009	-0.006	-0.006	-0.010	-0.010	0	0	0	-0.738	-0.301	-0.009	-0.009	-1.002	-1.002	-1.002	-0.010	-1.002	-0.010	-0.738	-0.738	-0.738	-1.002	-0.738	-0.738	-0.738	-0.012	-0.006	0.166	0.166	0.166	0.738	0	-0.154	-0.292	-0.300	0.683	0.895	-0.076	0.916	-0.036	0.687	0.706	-0.728	-0.264	-0.002	-0.004	-0.022	0	-0.012	0	0	0	0	-0.005	-0.001
21	-0.396	-0.396	0	0	0	0	0	0	0	0	0	-0.720	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.029	0	0.396	0.396	0.396	0	0	-0.367	-0.720	-0.739	-0.764	0	0	0	0	0	0	0	0	0	0	0	0	-0.028	-0.001	0	0	0	0	0
22	-0.047	-0.047	-0.009	-0.006	-0.006	-0.010	-0.010	0	0	0	-0.756	-0.085	-0.009	-0.009	-0.026	-0.026	-1.026	-0.010	-1.026	-0.010	-0.756	-0.756	-0.756	-1.026	-0.756	-0.756	-0.756	-0.003	-0.006	0.047	0.047	0.047	0.756	0	-0.044	-0.077	-0.079	-0.064	0.917	-0.078	0.938	-0.037	0.704	0.723	-0.745	0.729	-0.002	-0.004	-0.022	0	-0.003	0	0	0	0	-0.005	-0.001
23	-0.387	-0.387	0	0	0	0	0	0	0	0	0	-0.703	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.028	0	0.387	0.387	0.387	0	0	-0.359	-0.703	-0.722	-0.746	-0.977	0	0	0	0	0	0	0	0	0	0	0	-0.027	-0.001	0	0	0	0	0
24	-0.386	-0.386	0	0	0	0	0	0	0	0	0	-0.701	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.028	0	0.386	0.386	0.386	0	0	-0.358	-0.701	-0.720	-0.744	-0.974	-0.997	0	0	0	0	0	0	0	0	0	0	-0.027	-0.001	0	0	0	0	0
25	-0.038	-0.038	-0.009	-0.006	-0.006	-0.010	-0.010	0	0	0	-0.756	-0.069	-0.009	-0.009	-0.026	-0.026	-0.026	-0.010	-1.026	-0.010	-0.756	-0.756	-0.756	-1.026	-0.756	-0.756	-0.756	-0.003	-0.006	0.038	0.038	0.038	0.756	0	-0.035	-0.060	-0.062	-0.046	-0.060	-0.078	0.938	-0.037	0.704	0.723	-0.745	0.729	-0.002	-0.004	-0.022	0	-0.003	0	0	0	0	-0.005	-0.001
26	-0.369	-0.369	0	0	0	0	0	0	0	0	0	-0.671	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.027	0	0.369	0.369	0.369	0	0	-0.343	-0.671	-0.689	-0.712	-0.933	-0.955	-0.958	0	0	0	0	0	0	0	0	0	-0.026	-0.001	0	0	0	0	0
27	-0.048	-0.048	-0.002	0	0	-0.002	-0.002	0	0	0	-0.273	-0.087	-0.002	-0.002	-0.008	-0.008	-0.008	-0.002	-0.008	-1.002	-0.273	-0.273	-0.273	-0.008	-0.273	-0.273	-0.273	-0.003	0	0.048	0.048	0.048	0.273	0	-0.044	-0.085	-0.087	-0.084	-0.110	-0.118	-0.113	0.877	0.254	0.261	0.729	0.265	-0.001	-0.002	-0.008	0	-0.003	0	0	0	0	0	0
28	-0.329	-0.329	0	0	0	0	0	0	0	0	0	-0.598	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.024	0	0.329	0.329	0.329	0	0	-0.305	-0.598	-0.614	-0.635	-0.831	-0.851	-0.854	-0.891	0	0	0	0	0	0	0	0	-0.023	-0.001	0	0	0	0	0
29	-0.028	-0.028	-0.006	-0.002	-0.002	-0.009	-0.009	0	0	0	-1.025	-0.051	-0.006	-0.006	-0.030	-0.030	-0.030	-0.009	-0.030	-0.009	-1.025	-0.025	-1.025	-0.030	-1.025	-1.025	-1.025	-0.002	-0.002	0.028	0.028	0.028	1.025	0	-0.026	-0.045	-0.046	-0.024	-0.031	-0.053	-0.032	-0.055	0.954	0.980	-0.016	0.994	-0.004	-0.007	-0.030	0	-0.002	0	0	0	-0.001	0	-0.001
30	-0.008	-0.008	-0.002	0	0	-0.002	-0.002	0	0	0	-0.273	-0.014	-0.002	-0.002	-0.008	-0.008	-0.008	-0.002	-0.008	-0.002	-0.273	-0.273	-0.273	-0.008	-0.273	-0.273	-0.273	-0.001	0	0.008	0.008	0.008	0.273	0	-0.007	-0.012	-0.012	-0.006	-0.008	-0.014	-0.009	-0.015	0.254	0.261	0.729	0.265	-0.001	-0.002	-0.008	0	-0.001	0	0	0	0	0	0
31	-0.321	-0.321	0	0	0	0	0	0	0	0	0	-0.583	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.023	0	0.321	0.321	0.321	0	0	-0.297	-0.583	-0.598	-0.618	-0.809	-0.828	-0.831	-0.868	-0.974	0	0	0	0	0	0	0	-0.023	-0.001	0	0	0	0	0
32	-0.307	-0.307	0	0	0	0	0	0	0	0	0	-0.557	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.022	0	0.307	0.307	0.307	0	0	-0.284	-0.557	-0.572	-0.591	-0.774	-0.792	-0.795	-0.830	-0.931	-0.957	0	0	0	0	0	0	-0.022	-0.001	0	0	0	0	0
33	-0.022	-0.022	-0.009	-0.006	-0.006	-0.010	-0.010	0	0	0	-0.756	-0.039	-0.009	-0.009	-0.026	-0.026	-0.026	-0.010	-0.026	-0.010	-0.756	-0.756	-0.756	-1.026	-0.756	-0.756	-0.756	-0.002	-0.006	0.022	0.022	0.022	0.756	0	-0.020	-0.031	-0.032	-0.015	-0.019	-0.036	-0.020	-0.037	0.704	0.723	-0.745	0.729	-0.002	-0.004	-0.022	0	-0.002	0	0	0	0	-0.005	-0.001
34	-0.019	-0.019	-0.006	-0.002	-0.002	-0.009	-0.009	0	0	0	-1.025	-0.035	-0.006	-0.006	-0.030	-0.030	-0.030	-0.009	-0.030	-0.009	-0.025	-0.025	-1.025	-0.030	-1.025	-1.025	-1.025	-0.001	-0.002	0.019	0.019	0.019	1.025	0	-0.018	-0.029	-0.030	-0.007	-0.009	-0.031	-0.009	-0.031	-0.019	0.980	-0.016	0.994	-0.004	-0.007	-0.030	0	-0.001	0	0	0	-0.001	0	-0.001
35	-0.015	-0.015	-0.005	-0.001	-0.001	-0.008	-0.008	0	0	0	-1.006	-0.028	-0.005	-0.005	-0.005	-0.005	-0.005	-0.008	-0.005	-0.008	-0.006	-0.006	-1.006	-0.005	-0.006	-0.006	-1.006	-0.001	-0.001	0.015	0.015	0.015	1.006	0	-0.014	-0.023	-0.023	-0.024	-0.031	-0.029	-0.032	-0.031	-0.037	0.962	-0.002	0.001	-0.004	-0.007	-0.030	0	-0.001	0	0	0	-0.001	0	0
36	-0.004	-0.004	0	0	0	0	0	0	0	0	-0.018	-0.007	0	0	-0.024	-0.024	-0.024	0	-0.024	0	-0.018	-0.018	-0.018	-0.024	-0.018	-0.018	-0.018	0	0	0.004	0.004	0.004	0.018	0	-0.004	-0.007	-0.007	0.017	0.022	-0.002	0.022	0.001	0.017	0.017	-0.018	0.994	0	0	-0.001	0	0	0	0	0	0	0	0
37	-0.001	-0.001	-0.005	-0.001	-0.001	-0.008	-0.008	0	0	0	-1.006	-0.003	-0.005	-0.005	-0.005	-0.005	-0.005	-0.008	-0.005	-0.008	-0.006	-0.006	-0.006	-0.005	-0.006	-0.006	-1.006	0	-0.001	0.001	0.001	0.001	1.006	0	-0.001	0.003	0.003	0.003	0.004	0.007	0.004	0.007	0.006	0.006	0.002	0.001	-0.004	-0.007	-0.030	0	0	0	0	0	-0.001	0	0
38	-0.550	-0.550	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.040	0	0.550	0.550	0.550	0	0	-0.510	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.039	-0.001	0	0	0	0	0
39	-0.021	-0.021	-0.004	-0.001	-0.001	-0.007	-0.007	0	0	0	-0.752	-0.038	-0.004	-0.004	-0.022	-0.022	-0.022	-0.007	-0.022	-0.007	-0.752	-0.752	-0.752	-0.022	-0.752	-0.752	-0.752	-0.002	-0.001	0.021	0.021	0.021	0.752	0	-0.019	-0.033	-0.034	-0.017	-0.023	-0.039	-0.023	-0.040	0.700	0.719	-0.745	0.729	-0.003	-0.005	-0.022	0	-0.001	0	0	0	0	0	-0.001
40	-0.019	-0.019	-0.005	-0.001	-0.001	-0.008	-0.008	0	0	0	-1.024	-0.035	-0.005	-0.005	-0.030	-0.030	-0.030	-0.008	-0.030	-0.008	-0.024	-0.024	-1.024	-0.030	-0.024	-1.024	-1.024	-0.001	-0.001	0.019	0.019	0.019	1.024	0	-0.018	-0.030	-0.031	-0.007	-0.010	-0.031	-0.010	-0.032	-0.020	0.980	-0.016	0.994	-0.005	-0.007	-0.030	0	-0.001	0	0	0	-0.001	0	0
41	-0.197	-0.197	-0.009	-0.006	-0.006	-0.010	-0.010	0	0	0	-0.738	-0.358	-1.009	-1.009	-1.002	-1.002	-1.002	-0.010	-1.002	-0.010	-0.738	-0.738	-0.738	-1.002	-0.738	-0.738	-0.738	-0.014	-0.006	0.197	0.197	0.197	0.738	0	-0.183	0.650	0.668	0.683	0.895	-0.076	0.916	-0.036	0.687	0.706	-0.728	-0.264	-0.002	-0.004	-0.022	0	-0.014	0	0	0	0	-0.005	-0.001
42	-0.049	-0.049	-0.002	0	0	-0.002	-0.002	0	0	0	-0.273	-0.089	-0.002	-0.002	-0.008	-0.008	-0.008	-1.002	-0.008	-1.002	-0.273	-0.273	-0.273	-0.008	-0.273	-0.273	-0.273	-0.004	0	0.049	0.049	0.049	0.273	0	-0.045	-0.087	-0.090	-0.086	-0.113	0.879	-0.113	0.877	0.254	0.261	0.729	0.265	-0.001	-0.002	-0.008	0	-0.003	0	0	0	0	0	0
43	-0.001	-0.001	-0.005	-0.001	-0.001	-0.008	-0.008	0	0	0	-1.006	-0.003	-0.005	-0.005	-0.005	-0.005	-0.005	-0.008	-0.005	-0.008	-0.006	-0.006	-0.006	-0.005	-0.006	-0.006	-0.006	0	-0.001	0.001	0.001	0.001	0.006	0	-0.001	0.003	0.003	0.003	0.004	0.007	0.004	0.007	0.006	0.006	0.002	0.001	-0.004	-0.007	-0.030	0	0	0	0	0	-0.001	0	0
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	-0.485	-0.485	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.035	0	0.485	0.485	0.485	0	0	0.550	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.034	-0.001	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	-0.450	-0.450	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.960	0	0.450	0.450	0.450	0	0	0.510	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.039	0.001	0	0	0	0	0
48	-0.034	-0.034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.073	0	0.034	0.034	0.034	0	0	0.039	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.073	0	0	0	0	0	0
49	-0.001	-0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.002	0	0.001	0.001	0.001	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.003	0	0	0	0	0
50	-0.077	-0.077	-0.395	-1.002	-0.002	-0.004	-0.004	0	0	0	-0.289	-0.141	-0.395	-0.395	-0.393	-0.393	-0.393	-0.004	-0.393	-0.004	-0.289	-0.289	-0.289	-0.393	-0.289	-0.289	-0.289	-0.006	-0.002	0.077	0.077	0.077	0.289	0	-0.072	0.255	0.262	0.268	0.351	-0.030	0.359	-0.014	0.269	0.277	-0.285	-0.104	0.607	-0.002	-0.009	0	-0.005	0	0	0	0	-0.002	0
51	-0.126	-0.126	-0.460	-0.003	-1.003	-0.755	-0.755	0	0	0	-0.540	-0.230	-0.460	-0.460	-0.462	-0.462	-0.462	-0.755	-0.462	-0.755	-0.540	-0.540	-0.540	-0.462	-0.540	-0.540	-0.540	-0.009	-0.003	0.126	0.126	0.126	0.540	0	-0.117	0.230	0.237	0.246	0.323	0.623	0.332	0.640	0.503	0.517	0.215	0.078	-0.457	0.248	-0.016	0	-0.009	0	0	0	0	-0.002	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	-0.199	-0.199	-0.834	-0.980	-0.980	-0.740	-0.740	0	0	0	-0.808	-0.361	-0.834	-0.834	-0.833	-0.833	-0.833	-0.740	-0.833	-0.740	-0.808	-0.808	-0.808	-0.833	-0.808	-0.808	-0.808	-0.014	-0.980	0.199	0.199	0.199	0.808	0	-0.184	0.473	0.486	0.501	0.656	0.578	0.674	0.610	0.753	0.773	-0.069	-0.025	0.146	0.240	-0.024	0	-0.014	0	0	0.019	0	0.001	0
54	-0.004	-0.004	-0.016	-0.019	-0.019	-0.014	-0.014	0	0	0	-0.016	-0.007	-0.016	-0.016	-0.016	-0.016	-0.016	-0.014	-0.016	-0.014	-0.016	-0.016	-0.016	-0.016	-0.016	-0.016	-0.016	0	-0.019	0.004	0.004	0.004	0.016	0	-0.004	0.009	0.009	0.010	0.013	0.011	0.013	0.012	0.015	0.015	-0.001	0	0.003	0.005	0	0	0	0	0	-0.019	0	0	0
55	0	0	-0.001	-0.001	-0.001	0	0	0	0	0	-0.001	0	-0.001	-0.001	-0.001	-0.001	-0.001	0	-0.001	0	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	0	-0.001	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	-0.001	0	0
56	-0.001	-0.001	-0.004	-0.005	-0.005	-0.004	-0.004	0	0	0	-0.004	-0.002	-0.004	-0.004	-0.004	-0.004	-0.004	-0.004	-0.004	-0.004	-0.004	-0.004	-0.004	-0.004	-0.004	-0.004	-0.004	0	-0.005	0.001	0.001	0.001	0.004	0	-0.001	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0	0	0.001	0.001	0	0	0	0	0	0	0	-0.005	0
57	0	0	-0.001	-0.001	-0.001	-0.001	-0.001	0	0	0	-0.001	0	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	0	-0.001	0	0	0	0.001	0	0	0	0	0	0.001	0	0.001	0.001	0.001	0.001	0	0	0	0	0	0	0	0	0	0	0	0	-0.001

X

Matrix $(\boldsymbol{A}_k)^{-1}$ operational state x_1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	-0.035	-1.035	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.075	0	1.035	0.035	0.035	0	0	0.040	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.075	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	-0.198	-0.198	-1.009	-0.007	-0.007	-0.011	-0.011	0	0	0	-0.741	-0.360	-1.009	-1.009	-1.003	-1.003	-1.003	-0.011	-1.003	-0.011	-0.741	-0.741	-0.741	-1.003	-0.741	-0.741	-0.741	-0.015	-0.007	0.198	0.198	0.198	0.741	0	-0.183	0.649	0.667	0.682	0.895	-0.076	0.916	-0.035	0.691	0.709	-0.730	-0.262	-0.003	-0.004	-0.022	0	-0.014	0	0	0	-0.001	-0.006	-0.001
6	-0.122	-0.122	-0.622	-0.004	-0.004	-0.007	-0.007	0	0	0	-0.457	-0.222	-0.622	-0.622	-0.618	-0.618	-0.618	-0.007	-0.618	-0.007	-0.457	-0.457	-0.457	-0.618	-0.457	-0.457	-0.457	-0.009	-0.004	0.122	0.122	0.122	0.457	0	-0.113	0.400	0.411	0.421	0.552	-0.047	0.565	-0.022	0.426	0.437	-0.450	-0.162	-0.618	-0.003	-0.014	0	-0.009	0	0	0	0	-0.003	0
7	-0.048	-0.048	-0.002	0	0	-0.003	-1.003	0	0	0	-0.271	-0.088	-0.002	-0.002	-0.008	-0.008	-0.008	-1.003	-0.008	-1.003	-0.271	-0.271	-0.271	-0.008	-0.271	-0.271	-0.271	-0.004	0	0.048	0.048	0.048	0.271	0	-0.045	-0.087	-0.089	-0.085	-0.112	0.880	-0.112	0.878	0.253	0.259	0.732	0.263	-0.001	-0.002	-0.008	0	-0.004	0	0	0	0	0	0
8	-0.170	-0.170	-0.624	-0.004	-0.004	-1.009	-1.009	0	0	0	-0.728	-0.310	-0.624	-0.624	-0.626	-0.626	-0.626	-1.009	-0.626	-1.009	-0.728	-0.728	-0.728	-0.626	-0.728	-0.728	-0.728	-0.013	-0.004	0.170	0.170	0.170	0.728	0	-0.158	0.314	0.322	0.335	0.440	0.833	0.453	0.856	0.678	0.697	0.282	0.101	-0.619	-0.005	-0.022	0	-0.012	0	0	0	-0.001	-0.003	-0.001
9	-0.046	-0.046	-0.170	-0.001	-0.001	-0.275	-0.275	0	0	0	-0.198	-0.084	-0.170	-0.170	-0.170	-0.170	-0.170	-0.275	-0.170	-0.275	-0.198	-0.198	-0.198	-0.170	-0.198	-0.198	-0.198	-0.003	-0.001	0.046	0.046	0.046	0.198	0	-0.043	0.085	0.088	0.091	0.120	0.227	0.123	0.233	0.185	0.190	0.077	0.028	-0.169	-0.273	-0.006	0	-0.003	0	0	0	0	-0.001	0
10	-0.049	-0.049	-0.183	-0.024	-0.024	-0.283	-0.283	-1.000	0	-1.000	-0.210	-0.090	-0.183	-0.183	-0.184	-0.184	-0.184	-0.283	-0.184	-0.283	-0.210	-0.210	-0.210	-0.184	-0.210	-0.210	-0.210	-0.004	-0.024	0.049	0.049	0.049	0.210	1.000	-0.046	0.093	0.096	0.100	0.131	0.233	0.135	0.239	0.196	0.201	0.073	0.026	-0.160	-0.259	0.024	0	-0.004	0	0	-0.022	0	-0.001	0
11	-0.004	-0.004	-0.019	-0.022	-0.022	-0.016	-0.016	0	0	-1.000	-0.018	-0.008	-0.019	-0.019	-0.019	-0.019	-0.019	-0.016	-0.019	-0.016	-0.018	-0.018	-0.018	-0.019	-0.018	-0.018	-0.018	0	-0.022	0.004	0.004	0.004	0.018	1.000	-0.004	0.011	0.011	0.011	0.015	0.013	0.015	0.014	0.017	0.017	-0.002	-0.001	0.004	0.006	-0.001	0	0	0	0	-0.022	0	0	0
12	-0.049	-0.049	-0.183	-0.024	-0.024	-0.283	-0.283	-1.000	-1.000	-1.000	-0.210	-0.090	-0.183	-0.183	-0.184	-0.184	-0.184	-0.283	-0.184	-0.283	-0.210	-0.210	-0.210	-0.184	-0.210	-0.210	-0.210	-0.004	-0.024	0.049	0.049	0.049	0.210	1.000	-0.046	0.093	0.096	0.100	0.131	0.233	0.135	0.239	0.196	0.201	0.073	0.026	-0.160	-0.259	0.024	0	-0.004	0	0	-0.022	0	-0.001	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	-0.001	-0.001	-0.005	0	0	-0.008	-0.008	0	0	0	-0.006	-0.003	-0.005	-0.005	-0.005	-0.005	-0.005	-0.008	-0.005	-0.008	-0.006	-0.006	-0.006	-0.005	-0.006	-0.006	-0.006	0	0	0.001	0.001	0.001	0.006	0	-0.001	0.003	0.003	0.003	0.004	0.007	0.004	0.007	0.006	0.006	0.002	0.001	-0.005	-0.008	-0.030	0	0	0	0	0	0	0	0
15	-0.549	-0.549	0	0	0	0	0	0	0	0	0	-1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.041	0	0.549	0.549	0.549	0	0	-0.508	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.040	-0.001	0	0	0	0	0
16	-0.534	-0.534	0	0	0	0	0	0	0	0	0	-0.974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.040	0	0.534	0.534	0.534	0	0	-0.494	-0.974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.039	-0.001	0	0	0	0	0
17	-0.183	-0.183	-0.009	-0.007	-0.007	-0.011	-0.011	0	0	0	-0.741	-0.334	-0.009	-1.009	-1.003	-1.003	-1.003	-0.011	-1.003	-0.011	-0.741	-0.741	-0.741	-1.003	-0.741	-0.741	-0.741	-0.014	-0.007	0.183	0.183	0.183	0.741	0	-0.169	-0.325	0.667	0.682	0.895	-0.076	0.916	-0.035	0.691	0.709	-0.730	-0.262	-0.003	-0.004	-0.022	0	-0.013	0	0	0	-0.001	-0.006	-0.001
18	-0.517	-0.517	0	0	0	0	0	0	0	0	0	-0.942	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.039	0	0.517	0.517	0.517	0	0	-0.478	-0.942	-0.968	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.038	-0.001	0	0	0	0	0
19	-0.170	-0.170	-0.009	-0.007	-0.007	-0.011	-0.011	0	0	0	-0.759	-0.310	-0.009	-0.009	-1.027	-0.027	-1.027	-0.011	-1.027	-0.011	-0.759	-0.759	-0.759	-1.027	-0.759	-0.759	-0.759	-0.013	-0.007	0.170	0.170	0.170	0.759	0	-0.157	-0.300	-0.309	0.699	0.917	-0.077	0.938	-0.036	0.707	0.726	-0.748	0.732	-0.003	-0.004	-0.023	0	-0.012	0	0	0	-0.001	-0.006	-0.001
20	-0.166	-0.166	-0.009	-0.007	-0.007	-0.011	-0.011	0	0	0	-0.741	-0.303	-0.009	-0.009	-1.003	-1.003	-1.003	-0.011	-1.003	-0.011	-0.741	-0.741	-0.741	-1.003	-0.741	-0.741	-0.741	-0.012	-0.007	0.166	0.166	0.166	0.741	0	-0.154	-0.293	-0.301	0.682	0.895	-0.076	0.916	-0.035	0.691	0.709	-0.730	-0.262	-0.003	-0.004	-0.022	0	-0.012	0	0	0	-0.001	-0.006	-0.001
21	-0.394	-0.394	0	0	0	0	0	0	0	0	0	-0.718	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.030	0	0.394	0.394	0.394	0	0	-0.364	-0.718	-0.738	-0.762	0	0	0	0	0	0	0	0	0	0	0	0	-0.029	-0.001	0	0	0	0	0
22	-0.047	-0.047	-0.009	-0.007	-0.007	-0.011	-0.011	0	0	0	-0.759	-0.086	-0.009	-0.009	-0.027	-0.027	-1.027	-0.011	-1.027	-0.011	-0.759	-0.759	-0.759	-1.027	-0.759	-0.759	-0.759	-0.004	-0.007	0.047	0.047	0.047	0.759	0	-0.043	-0.076	-0.078	-0.063	0.917	-0.077	0.938	-0.036	0.707	0.726	-0.748	0.732	-0.003	-0.004	-0.023	0	-0.003	0	0	0	-0.001	-0.006	-0.001
23	-0.385	-0.385	0	0	0	0	0	0	0	0	0	-0.702	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.029	0	0.385	0.385	0.385	0	0	-0.356	-0.702	-0.721	-0.745	-0.977	0	0	0	0	0	0	0	0	0	0	0	-0.028	-0.001	0	0	0	0	0
24	-0.384	-0.384	0	0	0	0	0	0	0	0	0	-0.699	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.029	0	0.384	0.384	0.384	0	0	-0.355	-0.699	-0.718	-0.742	-0.974	-0.997	0	0	0	0	0	0	0	0	0	0	-0.028	-0.001	0	0	0	0	0
25	-0.038	-0.038	-0.009	-0.007	-0.007	-0.011	-0.011	0	0	0	-0.759	-0.069	-0.009	-0.009	-0.027	-0.027	-0.027	-0.011	-1.027	-0.011	-0.759	-0.759	-0.759	-1.027	-0.759	-0.759	-0.759	-0.003	-0.007	0.038	0.038	0.038	0.759	0	-0.035	-0.060	-0.061	-0.046	-0.060	-0.077	0.938	-0.036	0.707	0.726	-0.748	0.732	-0.003	-0.004	-0.023	0	-0.003	0	0	0	-0.001	-0.006	-0.001
26	-0.367	-0.367	0	0	0	0	0	0	0	0	0	-0.670	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.028	0	0.367	0.367	0.367	0	0	-0.340	-0.670	-0.688	-0.711	-0.932	-0.954	-0.957	0	0	0	0	0	0	0	0	0	-0.027	-0.001	0	0	0	0	0
27	-0.047	-0.047	-0.002	0	0	-0.003	-0.003	0	0	0	-0.271	-0.086	-0.002	-0.002	-0.008	-0.008	-0.008	-0.003	-0.008	-1.003	-0.271	-0.271	-0.271	-0.008	-0.271	-0.271	-0.271	-0.004	0	0.047	0.047	0.047	0.271	0	-0.044	-0.084	-0.087	-0.083	-0.109	-0.117	-0.112	0.878	0.253	0.259	0.732	0.263	-0.001	-0.002	-0.008	0	-0.003	0	0	0	0	0	0
28	-0.328	-0.328	0	0	0	0	0	0	0	0	0	-0.597	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.025	0	0.328	0.328	0.328	0	0	-0.303	-0.597	-0.613	-0.634	-0.831	-0.851	-0.854	-0.892	0	0	0	0	0	0	0	0	-0.024	-0.001	0	0	0	0	0
29	-0.028	-0.028	-0.007	-0.002	-0.002	-0.010	-0.010	0	0	0	-1.025	-0.051	-0.007	-0.007	-0.031	-0.031	-0.031	-0.010	-0.031	-0.010	-1.025	-0.025	-1.025	-0.031	-1.025	-1.025	-1.025	-0.002	-0.002	0.028	0.028	0.028	1.025	0	-0.026	-0.044	-0.045	-0.023	-0.030	-0.052	-0.031	-0.053	0.956	0.982	-0.016	0.994	-0.005	-0.008	-0.031	0	-0.002	0	0	0	-0.001	0	-0.001
30	-0.007	-0.007	-0.002	0	0	-0.003	-0.003	0	0	0	-0.271	-0.013	-0.002	-0.002	-0.008	-0.008	-0.008	-0.003	-0.008	-0.003	-0.271	-0.271	-0.271	-0.008	-0.271	-0.271	-0.271	-0.001	0	0.007	0.007	0.007	0.271	0	-0.007	-0.012	-0.012	-0.006	-0.008	-0.014	-0.008	-0.014	0.253	0.259	0.732	0.263	-0.001	-0.002	-0.008	0	-0.001	0	0	0	0	0	0
31	-0.319	-0.319	0	0	0	0	0	0	0	0	0	-0.581	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.024	0	0.319	0.319	0.319	0	0	-0.295	-0.581	-0.597	-0.617	-0.809	-0.828	-0.831	-0.868	-0.974	0	0	0	0	0	0	0	-0.023	-0.001	0	0	0	0	0
32	-0.305	-0.305	0	0	0	0	0	0	0	0	0	-0.557	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.023	0	0.305	0.305	0.305	0	0	-0.282	-0.557	-0.572	-0.591	-0.775	-0.793	-0.796	-0.831	-0.932	-0.958	0	0	0	0	0	0	-0.022	-0.001	0	0	0	0	0
33	-0.022	-0.022	-0.009	-0.007	-0.007	-0.011	-0.011	0	0	0	-0.759	-0.039	-0.009	-0.009	-0.027	-0.027	-0.027	-0.011	-0.027	-0.011	-0.759	-0.759	-0.759	-1.027	-0.759	-0.759	-0.759	-0.002	-0.007	0.022	0.022	0.022	0.759	0	-0.020	-0.030	-0.031	-0.014	-0.018	-0.035	-0.019	-0.036	0.707	0.726	-0.748	0.732	-0.003	-0.004	-0.023	0	-0.002	0	0	0	-0.001	-0.006	-0.001
34	-0.019	-0.019	-0.007	-0.002	-0.002	-0.010	-0.010	0	0	0	-1.025	-0.035	-0.007	-0.007	-0.031	-0.031	-0.031	-0.010	-0.031	-0.010	-0.025	-0.025	-1.025	-0.031	-1.025	-1.025	-1.025	-0.001	-0.002	0.019	0.019	0.019	1.025	0	-0.018	-0.029	-0.029	-0.006	-0.008	-0.029	-0.008	-0.030	-0.018	0.982	-0.016	0.994	-0.005	-0.008	-0.031	0	-0.001	0	0	0	-0.001	0	-0.001
35	-0.015	-0.015	-0.006	-0.001	-0.001	-0.009	-0.009	0	0	0	-1.007	-0.027	-0.006	-0.006	-0.006	-0.006	-0.006	-0.009	-0.006	-0.009	-0.007	-0.007	-1.007	-0.006	-0.007	-0.007	-1.007	-0.001	-0.001	0.015	0.015	0.015	1.007	0	-0.014	-0.022	-0.022	-0.023	-0.030	-0.028	-0.031	-0.029	-0.035	0.964	0.002	0.001	-0.005	-0.008	-0.030	0	-0.001	0	0	0	-0.001	0	0
36	-0.004	-0.004	0	0	0	0	0	0	0	0	-0.018	-0.007	0	0	-0.024	-0.024	-0.024	0	-0.024	0	-0.018	-0.018	-0.018	-0.024	-0.018	-0.018	-0.018	0	0	0.004	0.004	0.004	0.018	0	-0.004	-0.007	-0.007	0.017	0.022	-0.002	0.022	-0.001	0.017	0.017	-0.018	0.994	0	0	-0.001	0	0	0	0	0	0	0	0
37	-0.002	-0.002	-0.006	-0.001	-0.001	-0.009	-0.009	0	0	0	-1.007	-0.003	-0.006	-0.006	-0.006	-0.006	-0.006	-0.009	-0.006	-0.009	-0.007	-0.007	-0.007	-0.006	-0.007	-0.007	-1.007	0	-0.001	0.002	0.002	0.002	1.007	0	-0.001	0.003	0.003	0.003	0.004	0.007	0.004	0.007	0.006	0.006	0.002	0.001	-0.005	-0.008	-0.030	0	0	0	0	0	-0.001	0	0
38	-0.549	-0.549	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.041	0	0.549	0.549	0.549	0	0	-0.508	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.040	-0.001	0	0	0	0	0
39	-0.021	-0.021	-0.005	-0.001	-0.001	-0.007	-0.007	0	0	0	-0.754	-0.037	-0.005	-0.005	-0.023	-0.023	-0.023	-0.007	-0.023	-0.007	-0.754	-0.754	-0.754	-0.023	-0.754	-0.754	-0.754	-0.002	-0.001	0.021	0.021	0.021	0.754	0	-0.019	-0.033	-0.033	-0.017	-0.022	-0.038	-0.023	-0.039	0.703	0.722	-0.747	0.732	-0.004	-0.006	-0.023	0	-0.001	0	0	0	-0.001	0	-0.001
40	-0.019	-0.019	-0.006	-0.001	-0.001	-0.009	-0.009	0	0	0	-1.025	-0.035	-0.006	-0.006	-0.030	-0.030	-0.030	-0.009	-0.030	-0.009	-0.025	-0.025	-1.025	-0.030	-0.025	-1.025	-1.025	-0.001	-0.001	0.019	0.019	0.019	1.025	0	-0.018	-0.029	-0.030	-0.007	-0.009	-0.030	-0.009	-0.030	-0.019	0.981	-0.015	0.994	-0.005	-0.008	-0.031	0	-0.001	0	0	0	-0.001	0	0
41	-0.198	-0.198	-0.009	-0.007	-0.007	-0.011	-0.011	0	0	0	-0.741	-0.360	-1.009	-1.009	-1.003	-1.003	-1.003	-0.011	-1.003	-0.011	-0.741	-0.741	-0.741	-1.003	-0.741	-0.741	-0.741	-0.015	-0.007	0.198	0.198	0.198	0.741	0	-0.183	0.649	0.667	0.682	0.895	-0.076	0.916	-0.035	0.691	0.709	-0.730	-0.262	-0.003	-0.004	-0.022	0	-0.014	0	0	0	-0.001	-0.006	-0.001
42	-0.048	-0.048	-0.002	0	0	-0.003	-0.003	0	0	0	-0.271	-0.088	-0.002	-0.002	-0.008	-0.008	-0.008	-1.003	-0.008	-1.003	-0.271	-0.271	-0.271	-0.008	-0.271	-0.271	-0.271	-0.004	0	0.048	0.048	0.048	0.271	0	-0.045	-0.087	-0.089	-0.085	-0.112	0.880	-0.112	0.878	0.253	0.259	0.732	0.263	-0.001	-0.002	-0.008	0	-0.004	0	0	0	0	0	0
43	-0.002	-0.002	-0.006	-0.001	-0.001	-0.009	-0.009	0	0	0	-1.007	-0.003	-0.006	-0.006	-0.006	-0.006	-0.006	-0.009	-0.006	-0.009	-0.007	-0.007	-0.007	-0.006	-0.007	-0.007	-0.007	0	-0.001	0.002	0.002	0.002	0.007	0	-0.001	0.003	0.003	0.003	0.004	0.007	0.004	0.007	0.006	0.006	0.002	0.001	-0.005	-0.008	-0.030	0	0	0	0	0	-0.001	0	0
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	-0.488	-0.488	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.037	0	0.488	0.488	0.488	0	0	0.549	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.035	-0.001	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	-0.451	-0.451	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.959	0	0.451	0.451	0.451	0	0	0.508	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.040	0.001	0	0	0	0	0
48	-0.035	-0.035	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.075	0	0.035	0.035	0.035	0	0	0.040	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.075	0	0	0	0	0	0
49	-0.001	-0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.002	0	0.001	0.001	0.001	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.003	0	0	0	0	0
50	-0.076	-0.076	-0.387	-1.003	-0.003	-0.004	-0.004	0	0	0	-0.284	-0.138	-0.387	-0.387	-0.385	-0.385	-0.385	-0.004	-0.385	-0.004	-0.284	-0.284	-0.284	-0.385	-0.284	-0.284	-0.284	-0.006	-0.003	0.076	0.076	0.076	0.284	0	-0.070	0.249	0.256	0.262	0.343	-0.029	0.351	-0.013	0.265	0.272	-0.280	-0.101	0.615	-0.002	-0.009	0	-0.006	0	0	0	0	-0.002	0
51	-0.124	-0.124	-0.454	-0.003	-1.003	-0.735	-0.735	0	0	0	-0.530	-0.226	-0.454	-0.454	-0.456	-0.456	-0.456	-0.735	-0.456	-0.735	-0.530	-0.530	-0.530	-0.456	-0.530	-0.530	-0.530	-0.009	-0.003	0.124	0.124	0.124	0.530	0	-0.115	0.228	0.234	0.244	0.320	0.606	0.330	0.623	0.494	0.507	0.205	0.074	-0.451	0.269	-0.016	0	-0.009	0	0	0	0	-0.003	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	-0.194	-0.194	-0.817	-0.976	-0.976	-0.717	-0.717	0	0	0	-0.790	-0.353	-0.817	-0.817	-0.816	-0.816	-0.816	-0.717	-0.816	-0.717	-0.790	-0.790	-0.790	-0.816	-0.790	-0.790	-0.790	-0.015	-0.976	0.194	0.194	0.194	0.790	0	-0.179	0.463	0.476	0.491	0.644	0.561	0.661	0.592	0.736	0.756	-0.073	-0.026	0.160	0.259	-0.024	0	-0.014	0	0	0.022	0	0.001	0
54	-0.004	-0.004	-0.019	-0.022	-0.022	-0.016	-0.016	0	0	0	-0.018	-0.008	-0.019	-0.019	-0.019	-0.019	-0.019	-0.016	-0.019	-0.016	-0.018	-0.018	-0.018	-0.019	-0.018	-0.018	-0.018	0	-0.022	0.004	0.004	0.004	0.018	0	-0.004	0.011	0.011	0.011	0.015	0.013	0.015	0.014	0.017	0.017	-0.002	-0.001	0.004	0.006	-0.001	0	0	0	0	-0.022	0	0	0
55	0	0	-0.001	-0.001	-0.001	-0.001	-0.001	0	0	0	-0.001	0	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	0	-0.001	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0.001	0.001	0	0	0	0	0	0	0	0	0	0	-0.001	0	0
56	-0.001	-0.001	-0.005	-0.005	-0.005	-0.004	-0.004	0	0	0	-0.004	-0.002	-0.005	-0.005	-0.005	-0.005	-0.005	-0.004	-0.005	-0.004	-0.004	-0.004	-0.004	-0.005	-0.004	-0.004	-0.004	0	-0.005	0.001	0.001	0.001	0.004	0	-0.001	0.003	0.003	0.003	0.004	0.003	0.004	0.003	0.004	0.004	0	0	0.001	0.001	0	0	0	0	0	0	0	-0.006	0
57	0	0	-0.001	-0.001	-0.001	-0.001	-0.001	0	0	0	-0.001	0	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	0	-0.001	0	0	0	0.001	0	0	0	0	0	0.001	0	0.001	0.001	0.001	0.001	0	0	0	0	0	0	0	0	0	0	0	0	-0.001

A6

Matrix $\mathbf{A}_z$ of equations of exergy cost balance equations for the reference state x_0.

i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
3	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
9	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
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18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	-1.027	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	-1.033	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	-1.310	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	-1.023	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	-1.003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	-1.044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	-1.122	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	-1.027	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	-1.045	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	-0.363	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	1.000	-1.645	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1.000	-3.976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	1.000	0	0	0	0	-33.615	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-50807.000	1.000	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	-13.210	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	-384.902	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-15050.150	1.000	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	-51.489	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	-1529.487	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	-194.874	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	-1205.942

Matrix $\mathbf{A_z}$ of equations of exergy cost balance equations for the operational state x_1

i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
3	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
9	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.889	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	-1.027	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	-1.033	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	-1.312	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	-1.024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	-1.003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	-1.044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	-1.122	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	-1.027	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	-1.044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	-0.359	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	1.000	-1.622	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1.000	-3.674	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	1.000	0	0	0	0	-33.099	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-51987.000	1.000	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	-12.717	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	-393.841	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-14240.843	1.000	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	-43.590	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	-1430.234	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	-180.630	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	-1124.869

A7

The inverse matrix of the exergy cost balance equation coefficients $(\mathbf{A_z})^{-1}$ for the reference state x_0.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0.608	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.608	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0.251	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.251	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	1.000	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0.007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.007	-0.030	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0.974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0.976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.976	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0.943	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.943	-0.968	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	1.000	0	1.000	0	0	0.734	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.734	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.976	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0.720	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.720	-0.739	-0.764	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	1.000	0	0	0.734	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.734	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0.703	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.703	-0.722	-0.746	-0.977	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0.701	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.701	-0.720	-0.744	-0.974	-0.997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0.734	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.734	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0.671	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.671	-0.689	-0.712	-0.933	-0.955	-0.958	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0.266	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.734	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0.598	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.598	-0.614	-0.635	-0.831	-0.851	-0.854	-0.891	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	1.000	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.266	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.734	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0.583	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.583	-0.598	-0.618	-0.809	-0.828	-0.831	-0.868	-0.974	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0.557	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.557	-0.572	-0.591	-0.774	-0.792	-0.795	-0.830	-0.931	-0.957	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.734	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.734	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.976	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0.532	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.532	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.734	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.734	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	1.000	1.000	0	0.976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.976	0	0	0	0	0	0	0	0	0	0	0

42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	1.000	0	0.266	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.734	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0.007	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.007	-0.030	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	0.468	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.532	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.927	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.070	0.002	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.070	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.070	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.003	0	0	0	0	0
50	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.975	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.019	0.001	0.005	0.001
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.019	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.001	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.005	0
57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.001

The inverse matrix of the exergy cost balance equation coefficients $(\mathbf{A_z})^{-1}$ for the operational state x_1.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0.616	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.616	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0.272	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.272	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	1.000	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0.008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.008	-0.030	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0.974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0.976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.976	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0.942	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.942	-0.968	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	1.000	0	1.000	0	0	0.736	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.736	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.976	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0.718	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.718	-0.738	-0.762	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	1.000	0	0	0.736	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.736	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0.702	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.702	-0.721	-0.745	-0.977	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0.699	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.699	-0.718	-0.742	-0.974	-0.997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0.736	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.736	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0.670	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.670	-0.688	-0.711	-0.932	-0.954	-0.957	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0.264	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.736	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0.597	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.597	-0.613	-0.634	-0.831	-0.851	-0.854	-0.892	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	1.000	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.264	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.736	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0.581	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.581	-0.597	-0.617	-0.809	-0.828	-0.831	-0.868	-0.974	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0.557	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.557	-0.572	-0.591	-0.775	-0.793	-0.796	-0.831	-0.932	-0.958	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.736	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.736	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.976	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0.529	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.529	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.736	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.736	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	1.000	1.000	0	0.976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.976	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	1.000	0	0.264	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.736	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0.008	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.008	-0.030	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	0.471	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.529	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.925	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.073	0.002	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.073	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.073	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.003	0	0	0	0	0
50	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.971	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.022	0.001	0.005	0.001
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.022	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.001	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.006	0
57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.001

A8

Matrix $\langle \boldsymbol{FP} \rangle$ for reference state x_0

Component i	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
2	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.002	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.070	0
6	0	0	0	0	0	0	0	0	0	0	0	0	1.000	1.000	0	0.976	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0.392	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0.749	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0.608	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	1.000	0	0.266	0	0	0	0	0	0	0
11	0	0	0	0	0	0.244	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	1.000	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.019
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001
17	0.518	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0.026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0.032	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0.225	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	1.000	0	1.000	0	0	0.734	0	1.000	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0.017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0.002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0.030	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0.073	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0.016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	1.000	1.000	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.005
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.024	0	0	0	0	0	0	1.000	0	0	0	1.000	0	0
34	0	0	0	0	0	0.007	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0.482	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	1.000	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Matrix $\langle \boldsymbol{FP} \rangle$ for operational state x_1

Component i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
2	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.002	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.073	0
6	0	0	0	0	0	0	0	0	0	0	0	0	1.000	1.000	0	0.976	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0.384	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0.728	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0.616	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	1.000	0	0.264	0	0	0	0	0	0	0
11	0	0	0	0	0	0.264	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	1.000	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.022
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001
17	0.516	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0.024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0.030	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0.233	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	1.000	0	1.000	0	0	0.736	0	1.000	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0.016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0.002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0.030	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0.073	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0.016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	1.000	1.000	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.005
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.024	0	0	0	0	0	0	1.000	0	0	0	1.000	0	0
34	0	0	0	0	0	0.008	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0.484	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	1.000	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

A9

Transposed matrix $\langle \boldsymbol{FP} \rangle$ for reference state x_0

Component i	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
2	0	0	0	0	0	0	0	0	0	0	0	0.532	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.468	0
3	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0.392	0	0.608	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000
9	0	0	0	0	0.749	0	0	0.244	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.007	0	0
10	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0.026	0.031	0.223	0	0.016	0.002	0.030	0.073	0.016	0	0.025	0	0	0	0	0	0
18	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0.976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.024	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0.266	0	0	0	0	0	0	0	0	0.734	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0
35	0.002	0.070	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0.019	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0.005	0.001	0	0	0	0

Transposed matrix $\langle \boldsymbol{FP} \rangle$ for operational state x_1

Component i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
2	0	0	0	0	0	0	0	0	0	0	0	0.529	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.471	0
3	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0.384	0	0.616	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000
9	0	0	0	0	0.728	0	0	0.264	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.008	0	0
10	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0.026	0.031	0.224	0	0.017	0.002	0.030	0.073	0.016	0	0.025	0	0	0	0	0	0
18	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0.976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.024	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0.264	0	0	0	0	0	0	0	0	0.736	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0
35	0.002	0.073	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0.022	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0.005	0.001	0	0	0	0

A10

Matrix **Fx** for reference state x_0.

Component i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
2	0	0	0	0	0	0	0	0	0	0	0	63137.81238	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55638	0
3	2555.161	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	6957.758	0	10786.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6018
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9864
9	0	0	0	0	11187.65	0	0	3646.970352	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	111.8196	0	0
10	0	0	0	0	0	4161.519	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	3556.651407	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	230.7684671	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.900534	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	1644.75395	1963.440959	14005.45	0	1032.7499	145.7481259	1857.705	4593.322204	991.3594367	0	1586.60405	0	0	0	0	0	0
18	0	0	1449.7943	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	1532.3327	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11354.94	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	14835.464	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	361.1676	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	892.1817	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	85.96486	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1446.455	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	3593.236	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	782.2079	0	0	0	0	0	0	0
27	0	0	0	0	0	0	525.0192	0	0	0	0	0	0	0	0	1445.521	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	846.3034	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	53.84205	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.688845	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1182.172	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	113.5257	0	0	0
35	132	3846	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	292.3	9.84	0	0	0	0	0	0	0	0	0	0	0	0	77.23	12.48	0	0	0	0

Matrix **Fx** for operational state x_1.

Component i	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
2	0	0	0	0	0	0	0	0	0	0	0	63137.81238	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55638	0
3	2555.161	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	6957.758	0	10786.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6018
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9864
9	0	0	0	0	11187.65	0	0	3646.970352	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	111.8196	0	0
10	0	0	0	0	0	4161.519	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	3556.651407	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	230.7684671	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.900534	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	1644.75395	1963.440959	14005.45	0	1032.7499	145.7481259	1857.705	4593.322204	991.3594367	0	1586.60405	0	0	0	0	0	0
18	0	0	1449.7943	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	1532.3327	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11354.94	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	14835.464	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	361.1676	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	892.1817	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	85.96486	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1446.455	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	3593.236	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	782.2079	0	0	0	0	0	0	0
27	0	0	0	0	0	0	525.0192	0	0	0	0	0	0	0	0	1445.521	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	846.3034	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	53.84205	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.688845	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1182.172	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	113.5257	0	0	0
35	132	3846	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	292.3	9.84	0	0	0	0	0	0	0	0	0	0	0	0	77.23	12.48	0	0	0	0

A11

Matrix „Fuel – Product (F – P)” for reference state x_0.

			2	3	6	7	8	9	10	11	12	13	16	17	18	19	20	21	22	23	24	25	26	27	28	30	31	32	34	35	36	
		F0	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	F22	F23	F24	F25	F26	F27	F28	F29	PRODUKT
	P0	0	3097.373	140241.590	0	0	0	0	0	0	0	13950.599	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.283	0	0	157289.845
2	P1	0	0	0	0	0	0	0	0	0	0	0	0	59826.534	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55638.000	0	115464.534
3	P2	0	2555.161	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2555.161
6	P3	0	0	0	0	6957.758	0	10786.035	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17743.793
7	P4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6018.000	6018.000
8	P5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9864.000	9864.000
9	P6	0	0	0	0	0	11187.653	0	0	3646.970	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	111.820	0	0	14946.443
10	P7	0	0	0	0	0	0	4161.519	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4161.519
11	P8	0	0	0	0	0	0	0	0	0	3556.651	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3556.651
12	P9	16755.383	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16755.383
13	P10	0	0	0	0	0	0	0	0	0	230.768	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	230.768
16	P11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.662	0	0	1.662
17	P12	0	0	0	0	0	0	0	0	0	0	0	0	0	1577.307	1882.138	13395.494	0	985.364	139.072	1771.443	4375.459	943.036	0	1509.129	0	0	0	0	0	0	26578.440
18	P13	0	0	0	1449.794	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1449.794
19	P14	0	0	0	1532.333	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1532.333
20	P15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11359.413	0	0	0	0	0	0	0	0	0	0	0	0	0	11359.413
21	P16	0	0	0	14835.464	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	361.168	0	0	0	15196.632
22	P17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	892.182	0	0	0	0	0	0	0	0	0	0	0	0	0	892.182
23	P18	0	0	0	0	0	0	0	85.965	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	85.965
24	P19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1446.455	0	0	0	0	0	0	0	0	0	0	0	0	0	1446.455
25	P20	0	0	0	0	0	0	0	3593.236	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3593.236
26	P21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	782.208	0	0	0	0	0	0	0	782.208
27	P22	0	0	0	0	0	0	0	525.019	0	0	0	0	0	0	0	0	1445.521	0	0	0	0	0	0	0	0	0	0	0	0	0	1970.540
28	P23	32963.051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	846.303	0	0	0	33809.354
30	P24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	53.842	0	0	0	0	0	0	0	0	0	0	0	0	0	53.842
31	P25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.689	0	0	0	0	0	0	0	6.689
32	P26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1182.172	0	0	0	0	0	0	0	1182.172
34	P27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	113.526	0	0	0	113.526
35	P28	50807.000	132.000	3846.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54785.000
36	P29	15050.150	0	0	0	0	0	0	0	0	0	292.300	9.840	0	0	0	0	0	0	0	0	0	0	0	0	77.230	12.480	0	0	0	0	15442.000
	Fuel	115575.584	5784.534	144087.590	17817.591	6957.758	11187.653	14947.554	4204.220	3646.970	3787.420	14242.899	9.840	59826.534	1577.307	1882.138	13395.494	15197.414	985.364	139.072	1771.443	4375.459	943.036	1971.069	1509.129	77.230	12.480	1320.997	113.765	55638.000	15882.000	

Matrix „Fuel – Product (F – P)" for operational state x_1.

			2	3	6	7	8	9	10	11	12	13	16	17	18	19	20	21	22	23	24	25	26	27	28	30	31	32	34	35	36	
		F0	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	F22	F23	F24	F25	F26	F27	F28	F29	PRODUKT
	P0	0	3140.464	143358.069	0	0	0	0	0	0	0	14582.390	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.287	0	0	161081.211
2	P1	0	0	0	0	0	0	0	0	0	0	0	0	60875.208	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57078.000	0	117953.208
3	P2	0	2635.206	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2635.206
6	P3	0	0	0	0	6958.598	0	11186.033	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18144.631
7	P4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5753.000	5753.000
8	P5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9339.000	9339.000
9	P6	0	0	0	0	0	11198.764	0	0	4061.192	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	126.523	0	0	15386.478
10	P7	0	0	0	0	0	0	4208.694	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4208.694
11	P8	0	0	0	0	0	0	0	0	0	3718.012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3718.012
12	P9	18403.101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18403.101
13	P10	0	0	0	0	0	0	0	0	0	223.635	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	223.635
16	P11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.714	0	0	1.714
17	P12	0	0	0	0	0	0	0	0	0	0	0	0	0	1479.974	1791.217	14143.798	0	971.431	141.157	1813.600	4418.622	957.379	0	1502.007	0	0	0	0	0	0	27219.185
18	P13	0	0	0	1482.546	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1482.546
19	P14	0	0	0	1566.949	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1566.949
20	P15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11614.219	0	0	0	0	0	0	0	0	0	0	0	0	0	11614.219
21	P16	0	0	0	15170.603	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	368.205	0	0	0	15538.808
22	P17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	912.414	0	0	0	0	0	0	0	0	0	0	0	0	0	912.414
23	P18	0	0	0	0	0	0	0	86.939	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	86.939
24	P19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1479.257	0	0	0	0	0	0	0	0	0	0	0	0	0	1479.257
25	P20	0	0	0	0	0	0	0	3633.999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3633.999
26	P21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	797.315	0	0	0	0	0	0	0	797.315
27	P22	0	0	0	0	0	0	0	530.941	0	0	0	0	0	0	0	0	1478.302	0	0	0	0	0	0	0	0	0	0	0	0	0	2009.243
28	P23	33496.359	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	850.318	0	0	0	34346.677
30	P24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55.063	0	0	0	0	0	0	0	0	0	0	0	0	0	55.063
31	P25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.818	0	0	0	0	0	0	0	6.818
32	P26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1205.004	0	0	0	0	0	0	0	1205.004
34	P27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	128.382	0	0	0	128.382
35	P28	51987.000	132.000	4088.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56207.000
36	P29	14240.843	0	0	0	0	0	0	0	0	0	326.700	9.957	0	0	0	0	0	0	0	0	0	0	0	0	78.840	12.660	0	0	0	0	14669.000
	Fuel	118127.302	5907.671	147446.069	18220.097	6958.598	11198.764	15394.728	4251.879	4061.192	3941.647	14909.090	9.957	60875.208	1479.974	1791.217	14143.798	15539.255	971.431	141.157	1813.600	4418.622	957.379	2009.137	1502.007	78.840	12.660	1346.906	128.524	57078.000	15092.000	

A12

The ⟨**KP**⟩ matrix for reference state x_0.

Component i	2	3	6	7	8	9	10	11	12	13	16	17	18	19	20	21	22	23	24	25	26	27	28	30	31	32	34	35	36
2	0	0	0	0	0	0	0	0	0	0	0	1.005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.016	0
3	0.022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	1.156	0	0.722	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.390
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.639
9	0	0	0	0	1.134	0	0	1.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.985	0	0
10	0	0	0	0	0	0.278	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0.212	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0.014	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.015	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	1.088	1.228	1.179	0	1.104	1.618	1.225	1.218	1.206	0	1.783	0	0	0	0	0	0
18	0	0	0.082	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0.086	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.747	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0.836	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.306	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.059	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0.021	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.095	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0.863	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.397	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0.126	0	0	0	0	0	0	0	0	0.095	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.716	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.004	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.003	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.600	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.096	0	0	0
35	0.001	1.505	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	1.267	5.920	0	0	0	0	0	0	0	0	0	0	0	0	1.434	1.866	0	0	0	0

The ⟨**KP**⟩ matrix for operational state x_1.

Component i	2	3	6	7	8	9	10	11	12	13	16	17	18	19	20	21	22	23	24	25	26	27	28	30	31	32	34	35	36
2	0	0	0	0	0	0	0	0	0	0	0	1.003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.015	0
3	0.022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	1.210	0	0.727	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.392
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.637
9	0	0	0	0	1.199	0	0	1.092	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.986	0	0
10	0	0	0	0	0	0.274	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0.202	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0.012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.013	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0.998	1.143	1.218	0	1.065	1.624	1.226	1.216	1.201	0	1.766	0	0	0	0	0	0
18	0	0	0.082	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0.086	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.747	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0.836	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.306	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.059	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0.021	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.095	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0.863	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.397	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0.126	0	0	0	0	0	0	0	0	0.095	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.706	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.004	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.003	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.600	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.107	0	0	0
35	0.001	1.551	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	1.461	5.809	0	0	0	0	0	0	0	0	0	0	0	0	1.432	1.857	0	0	0	0

A13

The $\Delta\langle \mathbf{KP} \rangle$ matrix of CCGT plant.

Component i	**2**	**3**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**30**	**31**	**32**	**34**	**35**	**36**
2	0	0	0	0	0	0	0	0	0	0	0	-0.002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0.053	0	0.005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.002
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.002
9	0	0	0	0	0.065	0	0	0.067	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0
10	0	0	0	0	0	-0.005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	-0.010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	-0.002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.001	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	-0.090	-0.085	0.039	0	-0.040	0.006	0.001	-0.002	-0.005	0	-0.017	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.010	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.011	0	0	0
35	0	0.046	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0.194	-0.111	0	0	0	0	0	0	0	0	0	0	0	0	-0.003	-0.009	0	0	0	0

A14

The unitary matrix $\mathbf{U}_\mathbf{D}$.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

A15

The product operator **IP**⟩ for reference state x_0

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	1.036	1.584	1.263	1.461	1.455	1.283	1.334	1.316	0.305	1.898	8.873	1.041	1.133	1.279	1.228	1.268	1.150	1.684	1.275	1.268	1.255	1.618	1.857	2.150	2.796	1.850	1.394	1.052	1.499
2	0.023	1.035	0.028	0.032	0.032	0.028	0.030	0.029	0.007	0.042	0.196	0.023	0.025	0.028	0.027	0.028	0.025	0.037	0.028	0.028	0.028	0.036	0.041	0.048	0.062	0.041	0.031	0.023	0.033
3	0	0	1.009	1.166	0.828	0.730	0.007	0.748	0.176	1.245	5.820	0	0	0	0	0.010	0	0	0	0	0	0.054	0	1.410	1.834	0.080	0.804	0	0.983
4	0	0	0.002	1.002	0.002	0.002	0.001	0.002	0.007	0.496	2.320	0	0	0	0	0.002	0	0	0	0	0	0.005	0	0.562	0.731	0.004	0.036	0	0.392
5	0	0	0.003	0.004	1.003	0.003	0.001	0.003	0.012	0.814	3.802	0	0	0	0	0.004	0	0	0	0	0	0.008	0	0.921	1.198	0.007	0.058	0	0.642
6	0	0	0.008	0.010	1.144	1.008	0.009	1.034	0.232	0.930	4.348	0	0	0	0	0.010	0	0	0	0	0	0.067	0	1.054	1.370	0.105	1.057	0	0.734
7	0	0	0.002	0.003	0.318	0.281	1.002	0.288	0.065	0.259	1.211	0	0	0	0	0.003	0	0	0	0	0	0.019	0	0.293	0.382	0.029	0.294	0	0.204
8	0	0	0	0	0	0	0	1.000	0.212	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0.014	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	1.001	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0.001	0.015	0	0
12	0	0	1.213	1.403	1.398	1.232	1.281	1.264	0.293	1.823	8.522	1.000	1.088	1.228	1.179	1.218	1.104	1.618	1.225	1.218	1.206	1.554	1.783	2.065	2.686	1.777	1.338	0	1.439
13	0	0	0.082	0.095	0.068	0.060	0.001	0.061	0.014	0.102	0.476	0	1.000	0	0	0.001	0	0	0	0	0	0.004	0	0.115	0.150	0.007	0.066	0	0.080
14	0	0	0.087	0.101	0.071	0.063	0.001	0.065	0.015	0.108	0.503	0	0	1.000	0	0.001	0	0	0	0	0	0.005	0	0.122	0.158	0.007	0.069	0	0.085
15	0	0	0.642	0.742	0.532	0.469	0.022	0.481	0.113	0.797	3.723	0	0	0	1.000	0.767	0	0	0	0	0	0.174	0	0.902	1.173	0.284	0.517	0	0.629
16	0	0	0.858	0.992	0.712	0.628	0.029	0.643	0.151	1.066	4.981	0	0	0	0	1.026	0	0	0	0	0	0.233	0	1.207	1.570	0.380	0.691	0	0.841
17	0	0	0.050	0.058	0.042	0.037	0.002	0.038	0.009	0.063	0.292	0	0	0	0	0.060	1.000	0	0	0	0	0.014	0	0.071	0.092	0.022	0.041	0	0.049
18	0	0	0	0	0.007	0.006	0.021	0.006	0.001	0.005	0.025	0	0	0	0	0	0	1.000	0	0	0	0	0	0.006	0.008	0.001	0.006	0	0.004
19	0	0	0.082	0.094	0.068	0.060	0.003	0.061	0.014	0.101	0.474	0	0	0	0	0.098	0	0	1.000	0	0	0.022	0	0.115	0.149	0.036	0.066	0	0.080
20	0	0	0.002	0.002	0.275	0.242	0.865	0.249	0.056	0.224	1.045	0	0	0	0	0.002	0	0	0	1.000	0	0.016	0	0.253	0.329	0.025	0.254	0	0.177
21	0	0	0.033	0.038	0.043	0.038	0.051	0.039	0.009	0.053	0.249	0	0	0	0	0.039	0	0	0	0	1.000	0.407	0	0.060	0.078	0.016	0.041	0	0.042
22	0	0	0.082	0.095	0.108	0.095	0.129	0.098	0.023	0.134	0.627	0	0	0	0	0.098	0	0	0	0	0	1.025	0	0.152	0.197	0.040	0.103	0	0.106
23	0	0	0.035	0.041	0.046	0.041	0.056	0.042	0.010	0.058	0.269	0	0	0	0	0.042	0	0	0	0	0	0.440	1.000	0.065	0.085	0.733	0.044	0	0.045
24	0	0	0.003	0.004	0.003	0.002	0	0.002	0.001	0.004	0.018	0	0	0	0	0.004	0	0	0	0	0	0.001	0	1.004	0.006	0.001	0.002	0	0.003
25	0	0	0	0	0	0	0	0	0	0	0.002	0	0	0	0	0	0	0	0	0	0	0.003	0	0.001	1.001	0	0	0	0
26	0	0	0.049	0.057	0.065	0.057	0.078	0.059	0.014	0.080	0.376	0	0	0	0	0.059	0	0	0	0	0	0.615	0	0.091	0.118	1.024	0.062	0	0.063
27	0	0	0.005	0.005	0.006	0.005	0.007	0.006	0.001	0.008	0.036	0	0	0	0	0.006	0	0	0	0	0	0.059	0	0.009	0.011	0.098	1.006	0	0.006
28	0.036	1.560	0.044	0.050	0.050	0.044	0.046	0.045	0.011	0.065	0.306	0.036	0.039	0.044	0.042	0.044	0.040	0.058	0.044	0.044	0.043	0.056	0.064	0.074	0.096	0.064	0.048	1.036	0.052
29	0	0	0.005	0.006	0.005	0.004	0.002	0.004	0.018	1.274	5.953	0	0	0	0	0.006	0	0	0	0	0	0.013	0	1.442	1.876	0.011	0.091	0	1.005

The product operator **IP**⟩ for operational state x_1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	1.038	1.635	1.270	1.536	1.544	1.287	1.330	1.406	0.312	2.316	9.208	1.040	1.039	1.189	1.267	1.295	1.108	1.689	1.276	1.265	1.249	1.610	1.838	2.270	2.943	1.841	1.392	1.054	1.585
2	0.023	1.037	0.028	0.034	0.034	0.029	0.030	0.031	0.007	0.052	0.206	0.023	0.023	0.027	0.028	0.029	0.025	0.038	0.028	0.028	0.028	0.036	0.041	0.051	0.066	0.041	0.031	0.024	0.035
3	0	0	1.009	1.221	0.882	0.736	0.008	0.804	0.181	1.520	6.044	0	0	0	0	0.011	0	0	0	0	0	0.060	0	1.490	1.932	0.089	0.806	0	1.040
4	0	0	0.002	1.003	0.002	0.002	0.001	0.002	0.007	0.576	2.291	0	0	0	0	0.002	0	0	0	0	0	0.005	0	0.565	0.732	0.004	0.032	0	0.394
5	0	0	0.003	0.004	1.003	0.003	0.001	0.003	0.012	0.935	3.720	0	0	0	0	0.004	0	0	0	0	0	0.008	0	0.917	1.189	0.007	0.052	0	0.640
6	0	0	0.009	0.011	1.210	1.009	0.009	1.102	0.236	1.132	4.501	0	0	0	0	0.011	0	0	0	0	0	0.074	0	1.109	1.439	0.116	1.055	0	0.775
7	0	0	0.003	0.003	0.331	0.276	1.003	0.302	0.065	0.310	1.231	0	0	0	0	0.003	0	0	0	0	0	0.020	0	0.303	0.394	0.032	0.289	0	0.212
8	0	0	0	0	0	0	0	1.000	0.202	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0.012	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	1.001	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0.001	0.013	0	0
12	0	0	1.221	1.477	1.484	1.237	1.279	1.351	0.300	2.226	8.850	1.000	0.998	1.143	1.218	1.244	1.065	1.624	1.226	1.216	1.201	1.547	1.766	2.181	2.829	1.769	1.337	0	1.524
13	0	0	0.082	0.100	0.072	0.060	0.001	0.066	0.015	0.124	0.494	0	1.000	0	0	0.001	0	0	0	0	0	0.005	0	0.122	0.158	0.007	0.066	0	0.085
14	0	0	0.087	0.105	0.076	0.064	0.001	0.069	0.016	0.131	0.522	0	0	1.000	0	0.001	0	0	0	0	0	0.005	0	0.129	0.167	0.008	0.070	0	0.090
15	0	0	0.642	0.776	0.567	0.473	0.022	0.516	0.116	0.972	3.866	0	0	0	1.000	0.768	0	0	0	0	0	0.178	0	0.953	1.236	0.290	0.518	0	0.665
16	0	0	0.859	1.039	0.759	0.633	0.030	0.691	0.155	1.301	5.172	0	0	0	0	1.027	0	0	0	0	0	0.238	0	1.275	1.653	0.388	0.692	0	0.890
17	0	0	0.050	0.061	0.045	0.037	0.002	0.041	0.009	0.076	0.304	0	0	0	0	0.060	1.000	0	0	0	0	0.014	0	0.075	0.097	0.023	0.041	0	0.052
18	0	0	0	0	0.007	0.006	0.021	0.006	0.001	0.006	0.025	0	0	0	0	0	0	1.000	0	0	0	0	0	0.006	0.008	0.001	0.006	0	0.004
19	0	0	0.082	0.099	0.072	0.060	0.003	0.066	0.015	0.124	0.492	0	0	0	0	0.098	0	0	1.000	0	0	0.023	0	0.121	0.157	0.037	0.066	0	0.085
20	0	0	0.002	0.003	0.286	0.238	0.866	0.260	0.056	0.267	1.063	0	0	0	0	0.003	0	0	0	1.000	0	0.018	0	0.262	0.340	0.027	0.249	0	0.183
21	0	0	0.033	0.039	0.045	0.038	0.051	0.041	0.009	0.065	0.257	0	0	0	0	0.039	0	0	0	0	1.000	0.407	0	0.063	0.082	0.016	0.041	0	0.044
22	0	0	0.082	0.099	0.114	0.095	0.129	0.104	0.023	0.163	0.647	0	0	0	0	0.098	0	0	0	0	0	1.025	0	0.160	0.207	0.041	0.102	0	0.111
23	0	0	0.035	0.042	0.048	0.040	0.055	0.044	0.010	0.069	0.274	0	0	0	0	0.042	0	0	0	0	0	0.434	1.000	0.068	0.088	0.723	0.043	0	0.047
24	0	0	0.003	0.004	0.003	0.002	0	0.002	0.001	0.005	0.018	0	0	0	0	0.004	0	0	0	0	0	0.001	0	1.005	0.006	0.001	0.002	0	0.003
25	0	0	0	0	0	0	0	0	0	0.001	0.002	0	0	0	0	0	0	0	0	0	0	0.003	0	0.001	1.001	0	0	0	0
26	0	0	0.049	0.059	0.068	0.057	0.078	0.062	0.014	0.098	0.388	0	0	0	0	0.059	0	0	0	0	0	0.615	0	0.096	0.124	1.025	0.061	0	0.067
27	0	0	0.005	0.006	0.007	0.006	0.008	0.007	0.001	0.010	0.041	0	0	0	0	0.006	0	0	0	0	0	0.066	0	0.010	0.013	0.109	1.007	0	0.007
28	0.037	1.610	0.045	0.055	0.055	0.046	0.048	0.050	0.011	0.083	0.329	0.037	0.037	0.043	0.045	0.046	0.040	0.060	0.046	0.045	0.045	0.058	0.066	0.081	0.105	0.066	0.050	1.038	0.057
29	0	0	0.005	0.006	0.005	0.004	0.002	0.005	0.019	1.469	5.842	0	0	0	0	0.006	0	0	0	0	0	0.013	0	1.440	1.868	0.011	0.082	0	1.006

A16

The diagonal matrix $\mathbf{K}_D$ for the reference state x_0.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	1.265	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	1.505	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	1.004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	1.156	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	1.134	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	1.010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	1.059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	1.267	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	5.920	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	1.005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	1.088	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	1.228	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.179	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.104	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.618	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.225	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.218	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.206	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.783	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.434	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.866	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.117	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.002	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.016	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.028

The diagonal matrix $\mathbf{K}_D$ for the operational state x_1.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	1.265	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	1.551	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	1.004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	1.210	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	1.199	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	1.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	1.010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1.092	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	1.007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	1.461	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	5.809	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	1.003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0.998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	1.143	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.218	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.065	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.624	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.226	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.216	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.201	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.766	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.432	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.857	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.118	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.001	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.015	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.029

The irreversibility operator **II**⟩ for the reference state x_0.

	2	3	6	7	8	9	10	11	12	13	16	17	18	19	20	21	22	23	24	25	26	27	28	30	31	32	34	35	36
1	0.274	0.419	0.334	0.387	0.385	0.340	0.353	0.348	0.081	0.502	2.349	0.276	0.300	0.339	0.325	0.336	0.304	0.446	0.338	0.336	0.332	0.428	0.491	0.569	0.740	0.490	0.369	0.279	0.397
2	0.012	0.523	0.014	0.016	0.016	0.014	0.015	0.015	0.003	0.021	0.099	0.012	0.013	0.014	0.014	0.014	0.013	0.019	0.014	0.014	0.014	0.018	0.021	0.024	0.031	0.021	0.016	0.012	0.017
3	0	0	0.004	0.005	0.003	0.003	0	0.003	0.001	0.005	0.024	0	0	0	0	0	0	0	0	0	0	0	0	0.006	0.008	0	0.003	0	0.004
4	0	0	0	0.157	0	0	0	0	0.001	0.078	0.362	0	0	0	0	0	0	0	0	0	0	0.001	0	0.088	0.114	0.001	0.006	0	0.061
5	0	0	0	0.001	0.135	0	0	0	0.002	0.109	0.510	0	0	0	0	0.001	0	0	0	0	0	0.001	0	0.124	0.161	0.001	0.008	0	0.086
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0.003	0.003	0.010	0.003	0.001	0.003	0.012	0	0	0	0	0	0	0	0	0	0	0	0	0.003	0.004	0	0.003	0	0.002
8	0	0	0	0	0	0	0	0.025	0.005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0.059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0.004	0.267	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0.001	0	0	0.001	4.923	0	0	0	0	0	0	0	0	0	0	0.004	0	0.001	0.001	0.007	0.072	0	0
12	0	0	0.006	0.007	0.007	0.006	0.006	0.006	0.001	0.009	0.041	0.005	0.005	0.006	0.006	0.006	0.005	0.008	0.006	0.006	0.006	0.007	0.009	0.010	0.013	0.009	0.006	0	0.007
13	0	0	0.007	0.008	0.006	0.005	0	0.005	0.001	0.009	0.042	0	0.088	0	0	0	0	0	0	0	0	0	0	0.010	0.013	0.001	0.006	0	0.007
14	0	0	0.020	0.023	0.016	0.014	0	0.015	0.003	0.025	0.115	0	0	0.228	0	0	0	0	0	0	0	0.001	0	0.028	0.036	0.002	0.016	0	0.019
15	0	0	0.115	0.133	0.095	0.084	0.004	0.086	0.020	0.143	0.667	0	0	0	0.179	0.138	0	0	0	0	0	0.031	0	0.162	0.210	0.051	0.093	0	0.113
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0.005	0.006	0.004	0.004	0	0.004	0.001	0.007	0.031	0	0	0	0	0.006	0.104	0	0	0	0	0.001	0	0.007	0.010	0.002	0.004	0	0.005
18	0	0	0	0	0.004	0.004	0.013	0.004	0.001	0.003	0.015	0	0	0	0	0	0	0.618	0	0	0	0	0	0.004	0.005	0	0.004	0	0.003
19	0	0	0.018	0.021	0.015	0.013	0.001	0.014	0.003	0.023	0.107	0	0	0	0	0.022	0	0	0.225	0	0	0.005	0	0.026	0.034	0.008	0.015	0	0.018
20	0	0	0	0.001	0.060	0.053	0.188	0.054	0.012	0.049	0.228	0	0	0	0	0.001	0	0	0	0.218	0	0.004	0	0.055	0.072	0.005	0.055	0	0.038
21	0	0	0.007	0.008	0.009	0.008	0.011	0.008	0.002	0.011	0.051	0	0	0	0	0.008	0	0	0	0	0.206	0.084	0	0.012	0.016	0.003	0.008	0	0.009
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0.028	0.032	0.036	0.032	0.043	0.033	0.008	0.045	0.211	0	0	0	0	0.033	0	0	0	0	0	0.345	0.783	0.051	0.066	0.574	0.035	0	0.036
24	0	0	0.001	0.002	0.001	0.001	0	0.001	0	0.002	0.008	0	0	0	0	0.002	0	0	0	0	0	0	0	0.436	0.002	0.001	0.001	0	0.001
25	0	0	0	0	0	0	0	0	0	0	0.002	0	0	0	0	0	0	0	0	0	0	0.003	0	0	0.866	0	0	0	0
26	0	0	0.006	0.007	0.008	0.007	0.009	0.007	0.002	0.009	0.044	0	0	0	0	0.007	0	0	0	0	0	0.072	0	0.011	0.014	0.120	0.007	0	0.007
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.002	0	0
28	0.001	0.024	0.001	0.001	0.001	0.001	0.001	0.001	0	0.001	0.005	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.016	0.001
29	0	0	0	0	0	0	0	0	0.001	0.036	0.170	0	0	0	0	0	0	0	0	0	0	0	0	0.041	0.053	0	0.003	0	0.029

The irreversibility operator **II**⟩ for the operational state x_1.

	2	3	6	7	8	9	10	11	12	13	16	17	18	19	20	21	22	23	24	25	26	27	28	30	31	32	34	35	36
1	0.275	0.434	0.337	0.408	0.410	0.342	0.353	0.373	0.083	0.615	2.444	0.276	0.276	0.316	0.336	0.344	0.294	0.448	0.339	0.336	0.332	0.427	0.488	0.603	0.781	0.489	0.369	0.280	0.421
2	0.013	0.571	0.016	0.019	0.019	0.016	0.016	0.017	0.004	0.029	0.113	0.013	0.013	0.015	0.016	0.016	0.014	0.021	0.016	0.016	0.015	0.020	0.023	0.028	0.036	0.023	0.017	0.013	0.020
3	0	0	0.004	0.005	0.004	0.003	0	0.003	0.001	0.006	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0.006	0.008	0	0.003	0	0.004
4	0	0	0	0.210	0	0	0	0	0.002	0.121	0.480	0	0	0	0	0.001	0	0	0	0	0	0.001	0	0.118	0.153	0.001	0.007	0	0.083
5	0	0	0.001	0.001	0.200	0.001	0	0.001	0.002	0.186	0.741	0	0	0	0	0.001	0	0	0	0	0	0.002	0	0.183	0.237	0.001	0.010	0	0.128
6	0	0	0	0	0.001	0.001	0	0.001	0	0.001	0.002	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0.001	0	0.001	0	0
7	0	0	0	0	0.003	0.003	0.010	0.003	0.001	0.003	0.013	0	0	0	0	0	0	0	0	0	0	0	0	0.003	0.004	0	0.003	0	0.002
8	0	0	0	0	0	0	0	0.092	0.019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0.007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0.006	0.461	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0.001	0	0	0.001	4.811	0	0	0	0	0	0	0	0	0	0	0.004	0	0.001	0.001	0.007	0.065	0	0
12	0	0	0.003	0.004	0.004	0.003	0.003	0.004	0.001	0.006	0.023	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.004	0.005	0.006	0.007	0.005	0.004	0	0.004
13	0	0	0	0	0	0	0	0	0	0	-0.001	0	-0.002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0.012	0.015	0.011	0.009	0	0.010	0.002	0.019	0.075	0	0	0.143	0	0	0	0	0	0	0	0.001	0	0.018	0.024	0.001	0.010	0	0.013
15	0	0	0.140	0.169	0.123	0.103	0.005	0.112	0.025	0.212	0.842	0	0	0	0.218	0.167	0	0	0	0	0	0.039	0	0.208	0.269	0.063	0.113	0	0.145
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0.003	0.004	0.003	0.002	0	0.003	0.001	0.005	0.020	0	0	0	0	0.004	0.065	0	0	0	0	0.001	0	0.005	0.006	0.001	0.003	0	0.003
18	0	0	0	0	0.004	0.004	0.013	0.004	0.001	0.004	0.016	0	0	0	0	0	0	0.624	0	0	0	0	0	0.004	0.005	0	0.004	0	0.003
19	0	0	0.018	0.022	0.016	0.014	0.001	0.015	0.003	0.028	0.111	0	0	0	0	0.022	0	0	0.226	0	0	0.005	0	0.027	0.036	0.008	0.015	0	0.019
20	0	0	0	0.001	0.062	0.051	0.187	0.056	0.012	0.058	0.230	0	0	0	0	0.001	0	0	0	0.216	0	0.004	0	0.057	0.073	0.006	0.054	0	0.040
21	0	0	0.007	0.008	0.009	0.008	0.010	0.008	0.002	0.013	0.052	0	0	0	0	0.008	0	0	0	0	0.201	0.082	0	0.013	0.016	0.003	0.008	0	0.009
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0.027	0.032	0.037	0.031	0.042	0.034	0.007	0.053	0.210	0	0	0	0	0.032	0	0	0	0	0	0.333	0.766	0.052	0.067	0.554	0.033	0	0.036
24	0	0	0.001	0.002	0.001	0.001	0	0.001	0	0.002	0.008	0	0	0	0	0.002	0	0	0	0	0	0	0	0.434	0.003	0.001	0.001	0	0.001
25	0	0	0	0	0	0	0	0	0	0	0.002	0	0	0	0	0	0	0	0	0	0	0.003	0	0	0.857	0	0	0	0
26	0	0	0.006	0.007	0.008	0.007	0.009	0.007	0.002	0.011	0.046	0	0	0	0	0.007	0	0	0	0	0	0.072	0	0.011	0.015	0.121	0.007	0	0.008
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0
28	0.001	0.025	0.001	0.001	0.001	0.001	0.001	0.001	0	0.001	0.005	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.016	0.001
29	0	0	0	0	0	0	0	0	0.001	0.042	0.168	0	0	0	0	0	0	0	0	0	0	0	0	0.042	0.054	0	0.002	0	0.029

A17

A matrix showing the process of product exergy cost formation for individual components in the x_0 reference state.

	2	**3**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**30**	**31**	**32**	**34**	**35**	**36**
0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	0.274	0.377	0.305	0.369	0.372	0.310	0.322	0.339	0.075	0.557	2.215	0.240	0.273	0.308	0.297	0.306	0.278	0.409	0.309	0.307	0.303	0.389	0.446	0.546	0.708	0.444	0.335	0.243	0.381
3	0.012	0.571	0.016	0.019	0.019	0.016	0.017	0.018	0.004	0.029	0.115	0.012	0.014	0.016	0.015	0.016	0.014	0.021	0.016	0.016	0.016	0.020	0.023	0.028	0.037	0.023	0.017	0.013	0.020
6	0	0	0.004	0.005	0.004	0.003	0	0.003	0.001	0.006	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0.006	0.008	0	0.003	0	0.004
7	0	0	0	0.210	0	0	0	0	0.002	0.121	0.480	0	0	0	0	0.001	0	0	0	0	0	0.001	0	0.118	0.153	0.001	0.007	0	0.083
8	0	0	0.001	0.001	0.200	0.001	0	0.001	0.002	0.186	0.741	0	0	0	0	0.001	0	0	0	0	0	0.002	0	0.183	0.237	0.001	0.010	0	0.128
9	0	0	0	0	0.001	0.001	0	0.001	0	0.001	0.002	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0.001	0	0.001	0	0
10	0	0	0	0	0.003	0.003	0.010	0.003	0.001	0.003	0.013	0	0	0	0	0	0	0	0	0	0	0	0	0.003	0.004	0	0.003	0	0.002
11	0	0	0	0	0	0	0	0.092	0.019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0.007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0.006	0.461	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0.001	0	0	0.001	4.811	0	0	0	0	0	0	0	0	0	0	0.004	0	0.001	0.001	0.007	0.065	0	0
17	0	0	0.006	0.007	0.007	0.006	0.006	0.007	0.001	0.011	0.044	0.005	0.005	0.006	0.006	0.006	0.006	0.008	0.006	0.006	0.006	0.008	0.009	0.011	0.014	0.009	0.007	0	0.008
18	0	0	0.011	0.013	0.010	0.008	0	0.009	0.002	0.017	0.067	0	0.135	0	0	0	0	0	0	0	0	0.001	0	0.016	0.021	0.001	0.009	0	0.011
19	0	0	0.024	0.030	0.021	0.018	0	0.019	0.004	0.037	0.146	0	0	0.280	0	0	0	0	0	0	0	0.001	0	0.036	0.047	0.002	0.019	0	0.025
20	0	0	0.150	0.181	0.132	0.110	0.005	0.120	0.027	0.226	0.901	0	0	0	0.233	0.179	0	0	0	0	0	0.041	0	0.222	0.288	0.068	0.121	0	0.155
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0.008	0.010	0.007	0.006	0	0.006	0.001	0.012	0.048	0	0	0	0	0.010	0.158	0	0	0	0	0.002	0	0.012	0.015	0.004	0.006	0	0.008
23	0	0	0	0	0.005	0.004	0.014	0.004	0.001	0.004	0.018	0	0	0	0	0	0	0.700	0	0	0	0	0	0.004	0.006	0	0.004	0	0.003
24	0	0	0.023	0.028	0.021	0.017	0.001	0.019	0.004	0.035	0.140	0	0	0	0	0.028	0	0	0.285	0	0	0.006	0	0.035	0.045	0.011	0.019	0	0.024
25	0	0	0.001	0.001	0.079	0.066	0.238	0.072	0.015	0.074	0.293	0	0	0	0	0.001	0	0	0	0.275	0	0.005	0	0.072	0.094	0.008	0.069	0	0.050
26	0	0	0.009	0.010	0.012	0.010	0.013	0.011	0.002	0.017	0.067	0	0	0	0	0.010	0	0	0	0	0.261	0.106	0	0.017	0.021	0.004	0.011	0	0.012
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0.030	0.036	0.041	0.034	0.047	0.038	0.008	0.059	0.234	0	0	0	0	0.036	0	0	0	0	0	0.371	0.856	0.058	0.075	0.619	0.037	0	0.040
30	0	0	0.001	0.002	0.001	0.001	0	0.001	0	0.002	0.008	0	0	0	0	0.002	0	0	0	0	0	0	0	0.434	0.003	0.001	0.001	0	0.001
31	0	0	0	0	0	0	0	0	0	0	0.002	0	0	0	0	0	0	0	0	0	0	0.003	0	0	0.857	0	0	0	0
32	0	0	0.006	0.007	0.008	0.007	0.009	0.007	0.002	0.011	0.046	0	0	0	0	0.007	0	0	0	0	0	0.072	0	0.011	0.015	0.121	0.007	0	0.008
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0
35	0.001	0.025	0.001	0.001	0.001	0.001	0.001	0.001	0	0.001	0.005	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.016	0.001
36	0	0	0	0	0	0	0	0	0.001	0.042	0.168	0	0	0	0	0	0	0	0	0	0	0	0	0.042	0.054	0	0.002	0	0.029
k*	1.286	1.966	1.568	1.813	1.807	1.593	1.656	1.633	1.212	2.357	11.015	1.293	1.406	1.588	1.524	1.574	1.428	2.091	1.583	1.574	1.558	2.009	2.305	2.669	3.472	2.297	1.733	1.306	1.861

A matrix showing the process of product exergy cost formation for individual components in the x_1 operational state.

	2	3	6	7	8	9	10	11	12	13	16	17	18	19	20	21	22	23	24	25	26	27	28	30	31	32	34	35	36
0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	0.275	0.377	0.305	0.369	0.372	0.310	0.322	0.339	0.075	0.557	2.215	0.240	0.273	0.308	0.297	0.306	0.278	0.409	0.309	0.307	0.303	0.389	0.446	0.546	0.708	0.444	0.335	0.243	0.381
3	0.012	0.571	0.016	0.019	0.019	0.016	0.017	0.018	0.004	0.029	0.115	0.012	0.014	0.016	0.015	0.016	0.014	0.021	0.016	0.016	0.016	0.020	0.023	0.028	0.037	0.023	0.017	0.013	0.020
6	0	0	0.004	0.005	0.004	0.003	0	0.003	0.001	0.006	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0.006	0.008	0	0.003	0	0.004
7	0	0	0	0.210	0	0	0	0	0.002	0.121	0.480	0	0	0	0	0.001	0	0	0	0	0	0.001	0	0.118	0.153	0.001	0.007	0	0.083
8	0	0	0.001	0.001	0.200	0.001	0	0.001	0.002	0.186	0.741	0	0	0	0	0.001	0	0	0	0	0	0.002	0	0.183	0.237	0.001	0.010	0	0.128
9	0	0	0	0	0.001	0.001	0	0.001	0	0.001	0.002	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0.001	0	0.001	0	0
10	0	0	0	0	0.003	0.003	0.010	0.003	0.001	0.003	0.013	0	0	0	0	0	0	0	0	0	0	0	0	0.003	0.004	0	0.003	0	0.002
11	0	0	0	0	0	0	0	0.092	0.019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0.007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0.006	0.461	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0.001	0	0	0.001	4.811	0	0	0	0	0	0	0	0	0	0	0.004	0	0.001	0.001	0.007	0.065	0	0
17	0	0	0.006	0.007	0.007	0.006	0.006	0.007	0.001	0.011	0.044	0.005	0.005	0.006	0.006	0.006	0.006	0.008	0.006	0.006	0.006	0.008	0.009	0.011	0.014	0.009	0.007	0	0.008
18	0	0	0.011	0.013	0.010	0.008	0	0.009	0.002	0.017	0.067	0	0.135	0	0	0	0	0	0	0	0	0.001	0	0.016	0.021	0.001	0.009	0	0.011
19	0	0	0.024	0.030	0.021	0.018	0	0.019	0.004	0.037	0.146	0	0	0.280	0	0	0	0	0	0	0	0.001	0	0.036	0.047	0.002	0.019	0	0.025
20	0	0	0.150	0.181	0.132	0.110	0.005	0.120	0.027	0.226	0.901	0	0	0	0.233	0.179	0	0	0	0	0	0.041	0	0.222	0.288	0.068	0.121	0	0.155
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0.008	0.010	0.007	0.006	0	0.006	0.001	0.012	0.048	0	0	0	0	0.010	0.158	0	0	0	0	0.002	0	0.012	0.015	0.004	0.006	0	0.008
23	0	0	0	0	0.005	0.004	0.014	0.004	0.001	0.004	0.018	0	0	0	0	0	0	0.700	0	0	0	0	0	0.004	0.006	0	0.004	0	0.003
24	0	0	0.023	0.028	0.021	0.017	0.001	0.019	0.004	0.035	0.140	0	0	0	0	0.028	0	0	0.285	0	0	0.006	0	0.035	0.045	0.011	0.019	0	0.024
25	0	0	0.001	0.001	0.079	0.066	0.238	0.072	0.015	0.074	0.293	0	0	0	0	0.001	0	0	0	0.275	0	0.005	0	0.072	0.094	0.008	0.069	0	0.050
26	0	0	0.009	0.010	0.012	0.010	0.013	0.011	0.002	0.017	0.067	0	0	0	0	0.010	0	0	0	0	0.261	0.106	0	0.017	0.021	0.004	0.011	0	0.012
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0.030	0.036	0.041	0.034	0.047	0.038	0.008	0.059	0.234	0	0	0	0	0.036	0	0	0	0	0	0.371	0.856	0.058	0.075	0.619	0.037	0	0.040
30	0	0	0.001	0.002	0.001	0.001	0	0.001	0	0.002	0.008	0	0	0	0	0.002	0	0	0	0	0	0	0	0.434	0.003	0.001	0.001	0	0.001
31	0	0	0	0	0	0	0	0	0	0	0.002	0	0	0	0	0	0	0	0	0	0	0.003	0	0	0.857	0	0	0	0
32	0	0	0.006	0.007	0.008	0.007	0.009	0.007	0.002	0.011	0.046	0	0	0	0	0.007	0	0	0	0	0	0.072	0	0.011	0.015	0.121	0.007	0	0.008
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0
35	0.001	0.025	0.001	0.001	0.001	0.001	0.001	0.001	0	0.001	0.005	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.016	0.001
36	0	0	0	0	0	0	0	0	0.001	0.042	0.168	0	0	0	0	0	0	0	0	0	0	0	0	0.042	0.054	0	0.002	0	0.029
k*	1.289	2.030	1.577	1.908	1.917	1.599	1.652	1.746	1.180	2.876	11.436	1.292	1.290	1.477	1.574	1.608	1.376	2.098	1.584	1.571	1.552	1.999	2.283	2.819	3.656	2.286	1.731	1.309	1.969

A18
Malfunction matrix for CCGT plant.

Comp:	2	3	6	7	8	9	10	11	12	13	16	17	18	19	20	21	22	23	24	25	26	27	28	30	31	32	34	35	36	
j=0	90.285	117.826	0	0	0	0	0	0	0	44.821	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.114	0	0	
j=1	0	0	0	0	0	0	0	0	0	0	0	-128.466	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-4.036	0	
j=2	24.445	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
j=3	0	0	0	321.373	0	80.091	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
j=4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38.161	
j=5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-32.871	
j=6	0	0	0	0	640.659	0	0	237.967	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.061	0	0	
j=7	0	0	0	0	0	-73.189	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
j=8	0	0	0	0	0	0	0	0	-171.531	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
j=9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
j=10	0	0	0	0	0	0	0	0	-27.156	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
j=11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.146	0	0	
j=12	0	0	0	0	0	0	0	0	0	0	0	0	-130.028	-130.492	438.002	0	-35.474	0.503	1.942	-6.401	-3.797	0	-14.213	0	0	0	0	0	0	
j=13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
j=14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
j=15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.949	0	0	0	0	0	0	0	0	0	0	0	0	0	
j=16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.061	0	0	0	
j=17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.140	0	0	0	0	0	0	0	0	0	0	0	0	0	
j=18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
j=19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.227	0	0	0	0	0	0	0	0	0	0	0	0	0	
j=20	0	0	0	0	0	0	0.030	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
j=21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.251	0	0	0	0	0	0	0	
j=22	0	0	0	0	0	0	-0.030	0	0	0	0	0	0	0	0	0.227	0	0	0	0	0	0	0	0	0	0	0	0	0	
j=23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-12.097	0	0	0	
j=24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.008	0	0	0	0	0	0	0	0	0	0	0	0	0	
j=25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.002	0	0	0	0	0	0	0	
j=26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.379	0	0	0	0	0	0	0	
j=27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12.424	0	0	0	
j=28	-2.785	117.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
j=29	0	0	0	0	0	0	0	0	0	44.821	-0.185	0	0	0	0	0	0	0	0	0	0	0	0	-0.138	-0.060	0	0	0	0	SUM:
SUM	**111.945**	**235.652**	**0**	**321.373**	**640.659**	**6.903**	**0**	**237.967**	**-198.688**	**89.641**	**-0.185**	**-128.466**	**-130.028**	**-130.492**	**438.002**	**-0.345**	**-35.474**	**0.503**	**1.942**	**-6.401**	**-3.797**	**-0.632**	**-14.213**	**-0.138**	**-0.060**	**0.389**	**-0.199**	**-4.036**	**5.290**	**1437.114**

A19

The diagonal matrix **P** of the exergy value of products for the reference state x_0.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
1	115464.534	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	2555.161	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	17743.793	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	6018.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	9864.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	14946.443	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	4161.519	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	3556.651	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	16755.383	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	230.768	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	1.662	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	59541.491	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	1449.794	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	1532.333	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11359.413	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15196.632	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	892.182	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	85.965	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1446.455	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3593.236	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	782.208	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1970.540	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	846.303	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	53.842	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.689	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1182.172	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	113.526	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54785.000	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15442.000

The matrix of the product of two matrices: the irreversibility operator matrix $\boldsymbol{II}\rangle(\boldsymbol{x_1})$ and matrix representing difference bestween specific exergy consumptions $\Delta\langle\boldsymbol{KP}\rangle$.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
1	0	0.013	0	0.018	0.022	0	0	0.023	-0.005	0.082	-0.047	-0.001	-0.025	-0.024	0.011	0	-0.011	0.002	0	0	-0.001	0	-0.005	-0.001	-0.004	-0.001	-0.003	0	0
2	0	0.001	0	0.001	0.001	0	0	0.001	0	0.004	-0.002	0	-0.001	-0.001	0	0	-0.001	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0.016	-0.009	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.001	0	-0.001	0	0.001
5	0	0	0	0	0	0	0	0	0	0.025	-0.014	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.001	0	-0.001	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	-0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	-0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	-0.006	0	0
12	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0.001	0.001	0	0	0.001	0	0.002	-0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0.007	0.007	0.001	0	0.007	-0.001	0.028	-0.016	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.001	0.001	-0.001	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0.001	0.001	0	0	0.001	0	0.004	-0.002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0.003	-0.001	0	0.003	-0.001	0.008	-0.004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0
21	0	0	0	0	0	0	0	0.001	0	0.002	-0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0.001	0.002	0	0	0.002	0	0.007	-0.004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.007	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0.002	-0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0.006	-0.003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

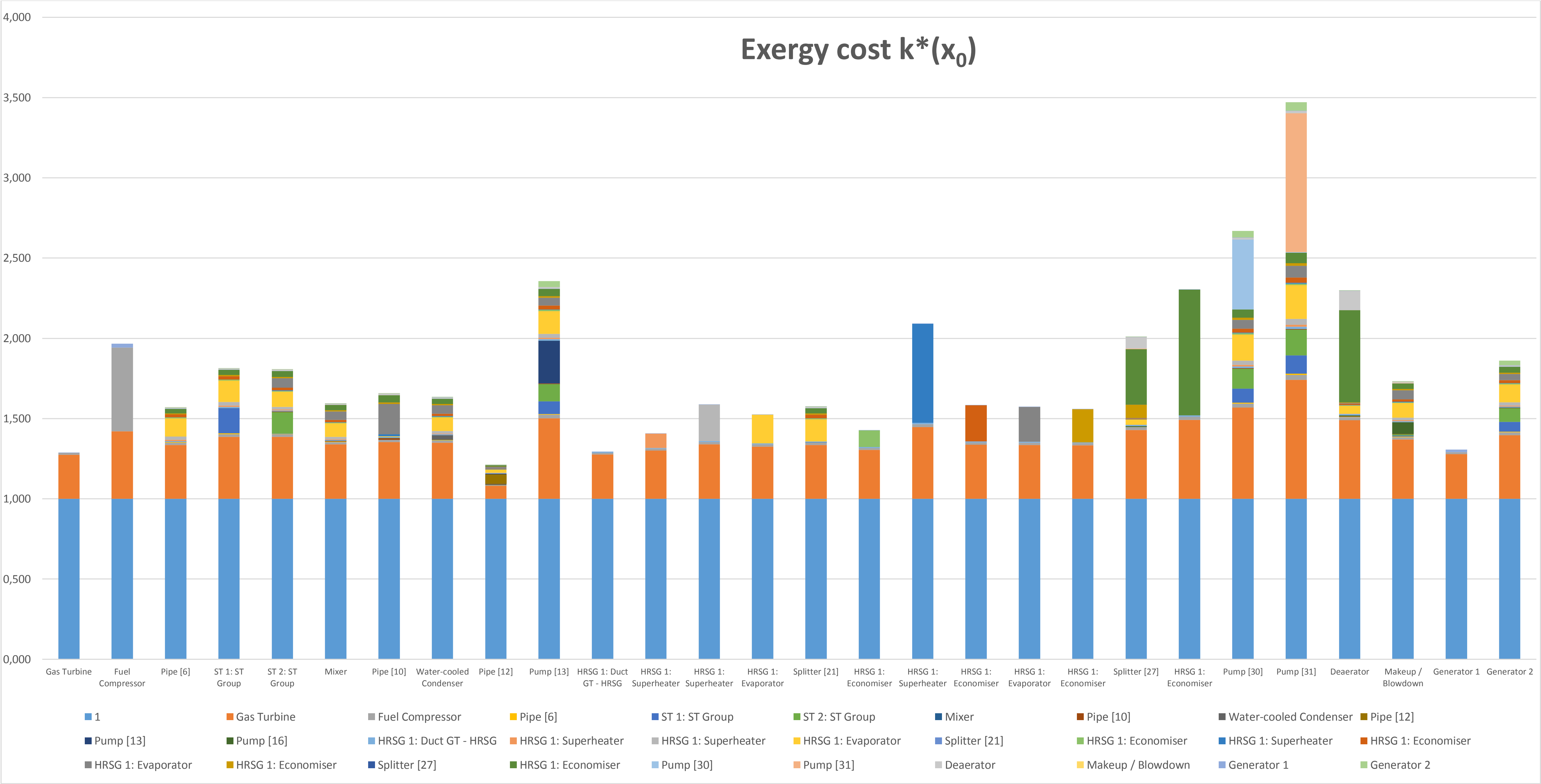
A20
Matrix of dysfunction of CCGT power plant.

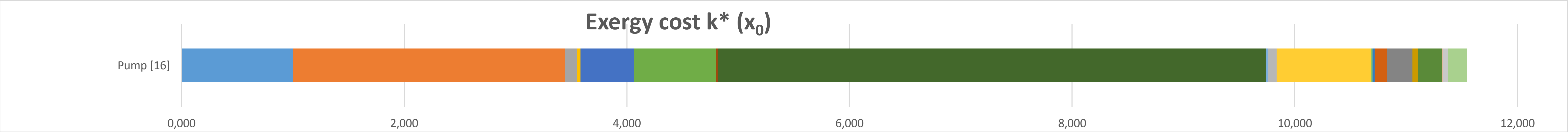
Component i	2	3	6	7	8	9	10	11	12	13	16	17	18	19	20	21	22	23	24	25	26	27	28	30	31	32	34	35	36	**DF_i**
2	9.829	32.961	0	108.352	218.919	1.157	-0.003	81.316	-80.718	18.861	-0.078	-35.389	-35.913	-36.042	120.976	-0.099	-9.798	0.139	0.536	-1.768	-1.049	-0.270	-3.926	-0.058	-0.025	-1.291	-0.337	-1.112	2.093	**387.265**
3	13.933	1.529	0	5.027	10.157	0.054	0	3.773	-3.745	0.875	-0.004	-1.642	-1.666	-1.672	5.613	-0.005	-0.455	0.006	0.025	-0.082	-0.049	-0.013	-0.182	-0.003	-0.001	-0.060	-0.016	-0.052	0.097	**31.444**
6	0	0	0	1.349	1.960	0.334	0	0.728	-0.745	0.194	-0.001	0	0	0	0	0	0	0	0	0	0	0	0	-0.001	0	0.042	-0.003	0	0.073	**3.930**
7	0	0	0	0.139	0.225	0.025	0	0.084	-3.345	3.705	-0.015	0	0	0	0	0.001	0	0	0	0	0	-0.001	0	-0.011	-0.005	0.084	-0.070	0	8.003	**8.819**
8	0	0	0	0.215	0.348	0.039	0	0.129	-5.160	5.715	-0.024	0	0	0	0	0.002	0	0	0	0	0	-0.001	0	-0.018	-0.008	0.130	-0.108	0	-6.536	**-5.278**
9	0	0	0	0.002	0.347	0	0	0.129	-0.118	0.019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.007	0	0	-0.021	**0.363**
10	0	0	0	0.008	1.815	-0.751	0	0.674	-0.617	0.097	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.037	-0.002	0	-0.110	**1.151**
11	0	0	0	0	0	0	0	0	-15.833	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**-15.833**
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
13	0	0	0	0	0	0	0	0	-12.515	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**-12.515**
16	0	0	0	0.108	0.250	-0.012	0	0.093	-0.091	0.020	0	0	0	0	0	0.001	0	0	0	0	0	-0.003	0	0	0	0.803	-0.704	0	0	**0.465**
17	0	0	0	1.032	2.084	0.011	0	0.774	-0.769	0.180	-0.001	0	-0.342	-0.343	1.152	-0.001	-0.093	0.001	0.005	-0.017	-0.010	-0.003	-0.037	-0.001	0	-0.012	-0.003	0	0.020	**3.627**
18	0	0	0	-0.046	-0.067	-0.011	0	-0.025	0.025	-0.007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.001	0	0	-0.002	**-0.134**
19	0	0	0	4.009	5.826	0.992	0	2.164	-2.214	0.576	-0.002	0	0	0	0	0	0	0	0	0	0	0	0	-0.002	-0.001	0.124	-0.010	0	0.217	**11.679**
20	0	0	0	44.930	65.973	10.839	-0.001	24.505	-25.044	6.496	-0.027	0	0	0	0	-0.196	0	0	0	0	0	-0.025	0	-0.020	-0.009	1.411	-0.117	0	2.394	**131.111**
21	0	0	0	0.008	0.012	0.002	0	0.004	-0.004	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0.023**
22	0	0	0	1.048	1.539	0.253	0	0.572	-0.584	0.152	-0.001	0	0	0	0	0.009	0	0	0	0	0	-0.001	0	0	0	0.033	-0.003	0	0.056	**3.073**
23	0	0	0	0.010	2.278	-0.943	0	0.846	-0.775	0.122	-0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.046	-0.002	0	-0.139	**1.444**
24	0	0	0	5.939	8.720	1.433	0	3.239	-3.310	0.859	-0.004	0	0	0	0	0.053	0	0	0	0	0	-0.003	0	-0.003	-0.001	0.186	-0.015	0	0.316	**17.408**
25	0	0	0	0.151	32.972	-13.642	0.006	12.247	-11.210	1.771	-0.007	0	0	0	0	0.001	0	0	0	0	0	-0.002	0	-0.005	-0.002	0.668	-0.030	0	-2.007	**20.910**
26	0	0	0	2.100	4.849	-0.231	-0.002	1.801	-1.770	0.398	-0.002	0	0	0	0	0.019	0	0	0	0	0	-0.052	0	-0.001	-0.001	0.102	-0.007	0	0.003	**7.206**
27	0	0	0	-0.001	-0.003	0	0	-0.001	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**-0.005**
28	0	0	0	8.550	19.742	-0.940	-0.010	7.333	-7.208	1.620	-0.007	0	0	0	0	0.076	0	0	0	0	0	-0.210	0	-0.005	-0.002	-8.857	-0.029	0	0.013	**20.067**
30	0	0	0	0.422	0.620	0.102	0	0.230	-0.235	0.061	0	0	0	0	0	0.004	0	0	0	0	0	0	0	0	0	0.013	-0.001	0	0.023	**1.238**
31	0	0	0	0.077	0.177	-0.008	0	0.066	-0.065	0.015	0	0	0	0	0	0.001	0	0	0	0	0	-0.002	0	0	0	0.004	0	0	0	**0.263**
32	0	0	0	1.862	4.299	-0.205	-0.002	1.597	-1.569	0.353	-0.001	0	0	0	0	0.017	0	0	0	0	0	-0.046	0	-0.001	0	0.090	-0.006	0	0.003	**6.388**
34	0	0	0	0.002	0.004	0	0	0.002	-0.002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.014	0	0	0	**0.020**
35	0.565	1.895	0	0.226	0.457	0.002	0	0.170	-0.169	0.039	0	-0.074	-0.075	-0.075	0.253	0	-0.020	0	0.001	-0.004	-0.002	-0.001	-0.008	0	0	-0.003	-0.001	-0.002	0.004	**3.179**
36	0	0	0	0.049	0.079	0.009	0	0.029	-1.174	1.300	-0.005	0	0	0	0	0	0	0	0	0	0	0	0	-0.004	-0.002	0.029	-0.025	0	0.002	**0.288**
(DF)	**24.327**	**36.385**	**0**	**185.567**	**383.583**	**-1.491**	**-0.013**	**142.479**	**-178.963**	**43.423**	**-0.179**	**-37.105**	**-37.997**	**-38.132**	**127.993**	**-0.116**	**-10.366**	**0.147**	**0.568**	**-1.870**	**-1.110**	**-0.632**	**-4.153**	**-0.134**	**-0.058**	**-6.402**	**-1.491**	**-1.166**	**4.504**	

Sum columns	627.598
Suma (DI)	627.598

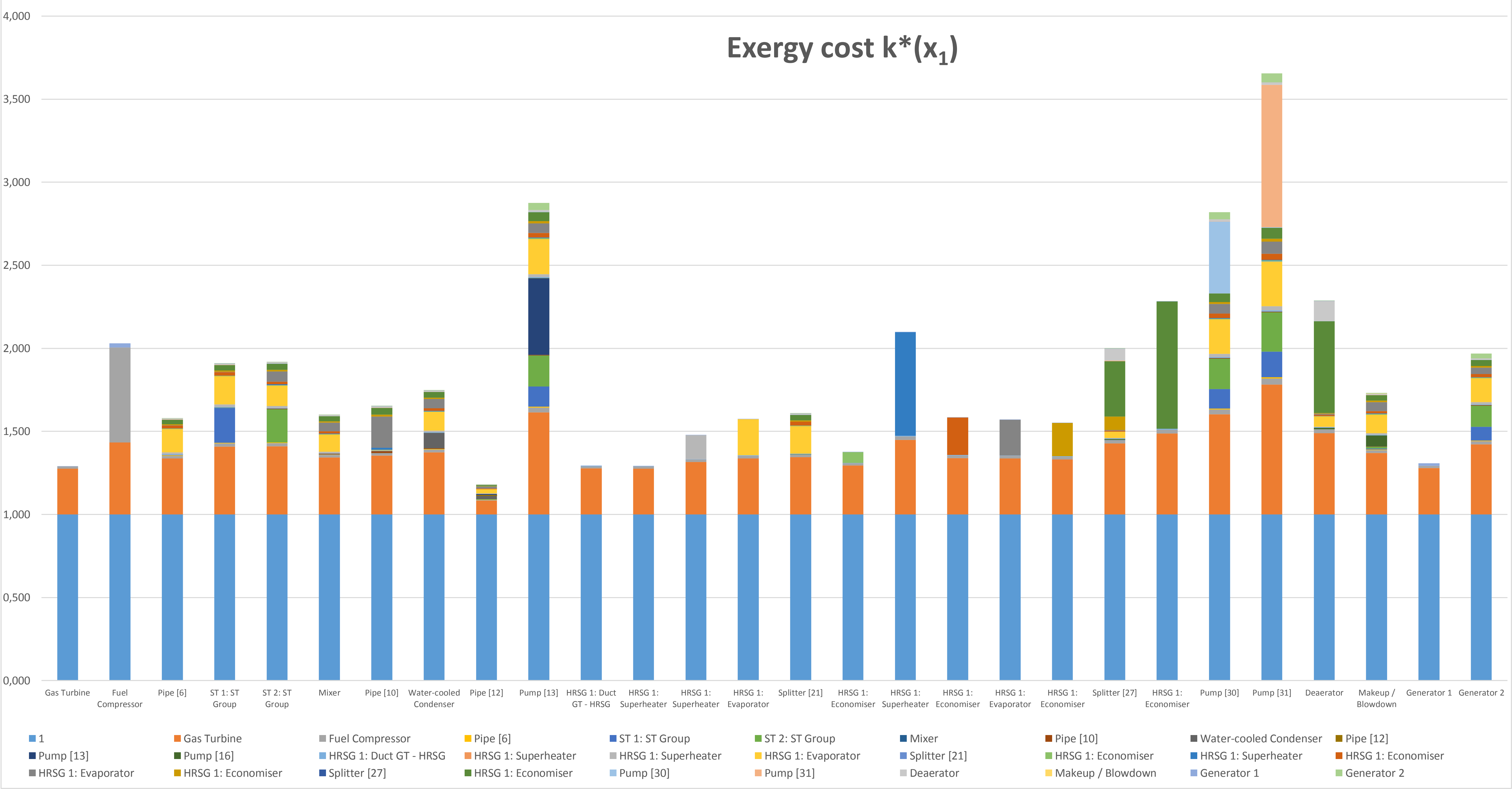
A21

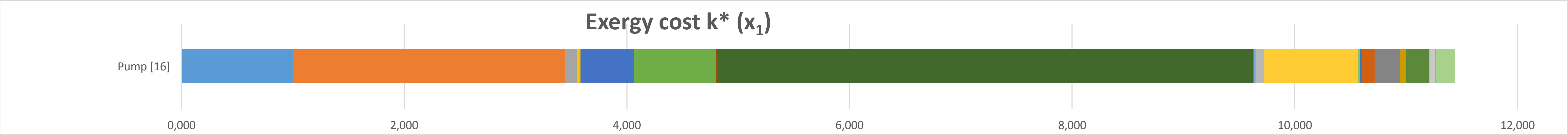
Graphical interpretation of exergy cost formation for all components of the CCGT plant in reference state x_0





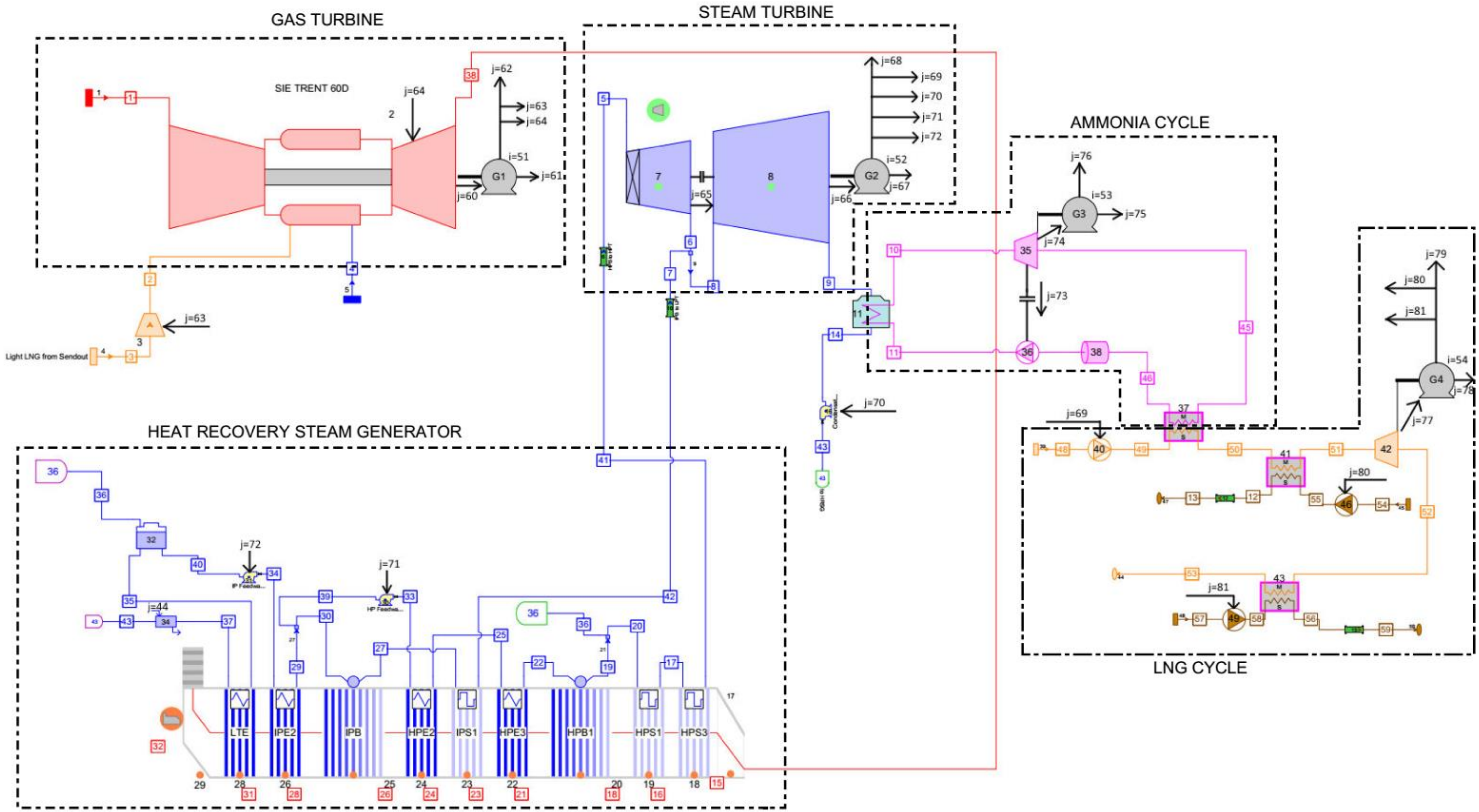
Graphical interpretation of exergy cost formation for all components of the CCGT plant in operational state x_1





B

CCGT integrated with LNG regasyfication system with all exergy flows defined



B1

List of components of the analyzed CCGT plant integrated with LNG regasification

Component number j	Description of the component
2	Gas Turbine
3	Fuel Compressor
6	Pipe
7	ST 1: ST Group
8	ST 2: ST Group
9	Mixer
10	Pipe
11	General Condenser
12	Pipe
13	Pipe
16	Pump
17	HRSG 1: Duct - GT to Horizontal HRSG
18	HRSG 1: Superheater
19	HRSG 1: Superheater
20	HRSG 1: Evaporator (PCE)
21	Splitter
22	HRSG 1: Economiser (PCE)
23	HRSG 1: Superheater (PCE)
24	HRSG 1: Economiser (PCE)
25	HRSG 1: Evaporator (PCE)
26	HRSG 1: Economiser (PCE)
27	Splitter
28	HRSG 1: Economiser (PCE)
30	Pump (PCE)
31	Pump (PCE)
32	Deaerator
34	Makeup / Blowdown
35	Refrigerant Turbine
36	Refrigerant Pump
37	General HX-SS
40	Fuel Pump
41	General HX-SS
42	Fuel Turbine
43	General HX-SS
46	Brine Pump
49	Brine Pump
51	Generator 1
52	Generator 2
53	Generator 3
54	Generator 4

B2

Comparison of thermodynamic parameters for individual flow streams for reference state x_0

Stream	j	p [bar]	T [°C]	m [kg/s]	h [kJ/kg]	s [kJ/kgK]	b_f [kJ/kg]
Air	1	1.013	20	154.4	20.117	0.000	19.867
Fuel	2	55.32	371.9	2.745	1824.431	6.638	1247.232
Fuel	3	1.034	2	2.745	832.356	6.413	316.390
Water	4	55.32	20	3.507	89.105	0.295	8.429
Steam	5	29	399	13.28	3231.104	6.938	1336.087
Steam	6	3.1	152.9	12.95	2766.645	7.077	833.482
Steam	7	3.1	164.2	4.939	2790.798	7.133	842.351
Steam	8	3.1	156	17.89	2773.314	7.093	835.891
Steam	9	0.04	28.98	18.21	2235.081	7.419	208.620
Ammonia	10	4	25	24.66	1670.822	6.355	484.509
Ammonia	11	4	-50.77	24.66	115.393	0.550	515.139
Sea Water	12	1.064	15	1475.6	57.559	0.191	8.015
Sea Water	13	1.014	15	1475.6	57.555	0.191	8.010
Water	14	0.3989	28.98	18.21	121.503	0.423	6.044
Flue Gas	15	1.032	420.4	159.9	895.815	7.730	372.369
Flue Gas	16	1.031	406.2	159.9	879.561	7.707	362.505
Steam	17	30.41	318.2	13.28	3038.624	6.611	1232.688
Flue Gas	18	1.03	388.8	159.9	859.720	7.677	350.667
Steam	19	30.99	235.7	13.6	2803.318	6.173	1117.119
Steam	20	30.99	235.7	13.28	2803.318	6.173	1117.119
Flue Gas	21	1.022	250.6	159.9	705.046	7.418	266.907
Water/Steam	22	30.99	231.6	13.67	997.752	2.624	280.895
Flue Gas	23	1.021	239	159.9	692.286	7.393	260.797
Flue Gas	24	1.021	237.3	159.9	690.419	7.390	259.927
Water/Steam	25	31.31	199.2	13.67	849.322	2.320	215.482
Flue Gas	26	1.019	215.3	159.9	666.314	7.342	248.849
Steam	27	3.434	138.2	4.939	2731.110	6.947	833.648
Flue Gas	28	1.016	153.2	159.9	598.835	7.195	221.485
Water	29	3.434	134.2	18.63	564.348	1.679	105.779
Water	30	3.434	134.2	4.964	564.348	1.679	105.779
Flue Gas	31	1.014	138	159.9	582.432	7.157	215.623
Flue Gas	32	1.013	110.1	159.9	552.425	7.081	206.180
Water	33	31.92	135	13.67	569.655	1.684	109.579
Water	34	3.537	101.2	18.63	424.415	1.321	63.696
Water	35	1.054	91.11	18.31	381.735	1.206	52.395
Steam	36	30.99	235.7	0.3242	2803.318	6.173	1117.119
Water	37	1.086	29.03	18.31	121.775	0.423	6.133
Flue Gas	38	1.037	422.4	159.9	898.108	7.732	374.152
Water	39	3.434	134.2	13.67	564.348	1.679	105.779
Water	40	1.054	101.1	18.63	423.807	1.319	63.421
Steam	41	29.94	400.8	13.28	3233.611	6.927	1341.438
Steam	42	3.302	166	4.939	2793.231	7.110	851.037
Water	43	1.086	29.07	18.21	121.942	0.424	6.149
Make-up water	44	1.086	20	0.094	84.014	0.296	3.026
Ammonia	45	0.4	-50.53	24.66	116.116	0.556	193.503
Ammonia	46	0.4	-51.03	24.66	113.939	0.546	514.706
LNG	48	1.41	-162	97.95	-1.742	-0.016	1243.957
LNG	49	150	-148.8	97.95	65.264	0.253	1259.817
LNG	50	150	-59.96	97.95	401.843	2.270	1138.187
LNG	51	150	9.98	97.95	710.682	3.530	987.315
LNG	52	84	-25.42	97.95	664.438	3.579	926.438
LNG	53	84	0.8116	97.95	753.674	3.922	923.734
Sea Water	54	1.014	20	1475.6	76.779	0.253	10.330
Sea Water	55	1.064	20	1475.6	76.783	0.253	10.335
Sea Water	56	1.064	15	423.4	57.559	0.191	8.015
Sea Water	57	1.014	20	423.4	76.779	0.253	10.330
Sea Water	58	1.064	20	423.4	76.783	0.253	10.335
Sea Water	59	1.014	15	423.4	57.555	0.191	8.010

Stream j	E [kW]
60	55638
61	853.3
62	50807
63	3846
64	132
65	6019
66	9860
67	439.6
68	8372.442
69	6968
70	9.838
71	77.24
72	12.48
73	28.38
74	5207
75	176.8
76	5030
77	4419
78	154.9
79	4244.49
80	15.04
81	4.47

Comparison of thermodynamic parameters for individual flow streams for operational state x_1

Stream	j	p [bar]	T [°C]	m [kg/s]	h [kJ/kg]	s [kJ/kgK]	b_f [kJ/kg]
Air	1	1.013	20	156.3	20.12	0.00	19.87
Fuel	2	55.32	371.9	2.801	1824.43	6.64	1247.23
Fuel	3	1.034	2	2.801	832.36	6.41	316.39
Water	4	55.32	20.02	3.652	89.19	0.30	8.43
Steam	5	29	399	13.55	3231.10	6.94	1336.09
Steam	6	3.1	162.8	13.22	2787.83	7.13	841.24
Steam	7	3.1	164.2	4.991	2790.80	7.13	842.35
Steam	8	3.1	163.2	18.21	2788.68	7.13	841.56
Steam	9	0.05	32.88	18.54	2560.74	8.39	267.95
Ammonia	10	4	25	25.61	1670.82	6.35	484.51
Ammonia	11	4	-50.77	25.61	115.39	0.55	515.14
Sea Water	12	1.064	15	1391.6	57.56	0.19	8.01
Sea Water	13	1.014	15	1391.6	57.55	0.19	8.01
Water	14	0.4089	32.89	18.54	137.85	0.48	7.71
Flue Gas	15	1.032	421.5	162	899.81	7.73	373.48
Flue Gas	16	1.031	407.2	162	883.42	7.71	363.52
Steam	17	30.41	318.2	13.55	3038.62	6.61	1232.69
Flue Gas	18	1.03	389.8	162	863.56	7.68	351.66
Steam	19	30.99	235.7	13.88	2803.32	6.17	1117.12
Steam	20	30.99	235.7	13.55	2803.32	6.17	1117.12
Flue Gas	21	1.022	250.7	162	707.72	7.42	267.21
Water/Steam	22	30.99	231.6	13.95	997.75	2.62	280.89
Flue Gas	23	1.021	238.9	162	694.72	7.39	260.99
Flue Gas	24	1.021	237.2	162	692.86	7.39	260.12
Water/Steam	25	31.31	199.2	13.95	849.32	2.32	215.48
Flue Gas	26	1.019	215	162	668.51	7.34	248.94
Steam	27	3.434	138.2	4.991	2731.11	6.95	833.65
Flue Gas	28	1.016	153.2	162	601.30	7.20	221.69
Water	29	3.434	134.2	18.96	564.35	1.68	105.78
Water	30	3.434	134.2	5.016	564.35	1.68	105.78
Flue Gas	31	1.014	137.9	162	584.78	7.16	215.79
Flue Gas	32	1.013	111.6	162	556.46	7.09	206.84
Water	33	31.92	135	13.95	569.66	1.68	109.58
Water	34	3.537	101.2	18.96	424.41	1.32	63.70
Water	35	1.054	91.11	18.64	381.73	1.21	52.39
Steam	36	30.99	235.7	0.3291	2803.32	6.17	1117.12
Water	37	1.086	32.92	18.64	138.03	0.48	7.79
Flue Gas	38	1.037	423.5	162	902.11	7.73	375.26
Water	39	3.434	134.2	13.95	564.35	1.68	105.78
Water	40	1.054	101.1	18.96	423.81	1.32	63.42
Steam	41	29.94	400.8	13.55	3233.61	6.93	1341.44
Steam	42	3.302	166	4.991	2793.23	7.11	851.04
Water	43	1.086	32.98	18.54	138.28	0.48	7.82
Make-up water	44	1.086	20	0.094	84.01	0.30	3.03
Ammonia	45	0.4	-50.53	25.61	116.12	0.56	193.50
Ammonia	46	0.4	-51.03	25.61	113.94	0.55	514.71
LNG	48	1.41	-162	97.95	-1.74	-0.02	1243.96
LNG	49	150	-147.5	97.95	69.68	0.29	1256.61
LNG	50	150	-56.18	97.95	419.12	2.35	1136.04
LNG	51	150	9.98	97.95	710.68	3.53	987.32
LNG	52	84	-24.96	97.95	666.19	3.59	926.34
LNG	53	84	0.8116	97.95	753.67	3.92	923.73
Sea Water	54	1.014	20	1391.6	76.78	0.25	10.33
Sea Water	55	1.064	20	1391.6	76.78	0.25	10.34
Sea Water	56	1.064	15	414.6	57.56	0.19	8.01
Sea Water	57	1.014	20	414.6	76.78	0.25	10.33
Sea Water	58	1.064	20	414.6	76.78	0.25	10.34
Sea Water	59	1.014	15	414.6	57.55	0.19	8.01

Stream j	E [kW]
60	56943
61	869.2
62	52016
63	3925
64	132
65	5843
66	9250
67	423.3
68	7134.65
69	7434
70	9.88
71	78.78
72	12.69
73	30.34
74	5405
75	182.1
76	5223
77	4249
78	150.1
79	4080.419
80	14.2
81	4.381

B3

Exergy values for CCGT plant integrated with LNG regasification for reference and operational conditions

Steam j	Stream	Exergy [kW] X_0	Exergy [kW] X_1	Steam j	Stream	Exergy [kW] X_0	Exergy [kW] X_1
1	Air	3067.535	3105.283	41	Steam	17814.3	18176.49
2	Fuel	3423.653	3493.498	42	Steam	4203.274	4247.528
3	Fuel	868.4913	886.2091	43	Water	111.9696	144.8989
4	Water	29.56093	30.80393	44	Make-up water	0.284406	0.284406
5	Steam	17743.23	18103.97	45	Ammonia	4771.789	4955.617
6	Steam	10793.59	11121.18	46	Ammonia	12692.66	13181.63
7	Steam	4160.373	4204.176	48	LNG	121845.6	121845.6
8	Steam	14954.09	15324.74	49	LNG	123399.1	123084.9
9	Steam	3798.968	4967.815	50	LNG	111485.4	111275.5
10	Ammonia	11947.98	12408.27	51	LNG	96707.54	96707.54
11	Ammonia	12703.33	13192.72	52	LNG	90744.56	90734.79
12	Bine	11826.66	11153.42	53	LNG	90479.77	90479.77
13	Bine	11819.71	11146.86	54	Brine	15243.53	14375.78
14	Water	110.066	142.9001	55	Brine	15250.48	14382.33
15	Flue Gas	59541.84	60503.38	56	Brine	3393.473	3322.943
16	Flue Gas	57964.52	58890.69	57	Brine	4373.889	4282.982
17	Steam	16370.1	16702.93	58	Brine	4375.883	4284.934
18	Flue Gas	56071.68	56968.83	59	Brine	3391.477	3320.988
19	Steam	15192.82	15505.61	60	Shaft power to G1	55638	56943
20	Steam	14835.34	15136.96	61	Heat from G1	853.3	869.2
21	Flue Gas	42678.38	43287.51	62	Net electricity from G1	50807	52016
22	Water/Steam	3839.832	3918.483	63	Power to Fuel Compressor	3846	3925
23	Flue Gas	41701.43	42280.01	64	Power to GT aux	132	132
24	Flue Gas	41562.36	42139.02	65	ST case 2 shaft power	6019	5843
25	Water/Steam	2945.645	3005.981	66	ST case 1 shaft power	9860	9250
26	Flue Gas	39790.91	40327.57	67	Heat from G2	439.6	423.3
27	Steam	4117.388	4160.737	68	Net electricity from G2	8372.442	7134.65
28	Flue Gas	35415.43	35914.19	69	Power to LNG pump	6968	7434
29	Water	1970.658	2005.565	70	Power to Pump 16	9.838	9.88
30	Water	525.0856	530.5861	71	Power to Pump 30	77.24	78.78
31	Flue Gas	34478.17	34957.94	72	Power to Pump 31	12.48	12.69
32	Flue Gas	32968.18	33508.04	73	Shaft power to ammonia pump	28.38	30.34
33	Water	1497.943	1528.625	74	Shaft power to G3	5207	5405
34	Water	1186.665	1207.685	75	Heat from G3	176.8	182.1
35	Water	959.3485	976.6388	76	Net electricity from G3	5030	5223
36	Steam	362.1699	367.6438	77	Shaft power to G4	4419	4249
37	Water	112.2902	145.1773	78	Heat from G4	154.9	150.1
38	Flue Gas	59826.88	60792.71	79	Net electricity from G4	4244.49	4080.419
39	Water	1445.995	1475.613	80	Power to Pump 46	15.04	14.2
40	Water	1181.538	1202.467	81	Power to Pump 49	4.47	4.381

B4

Values of vectors for exergy flows of fuels, products and irreversibility of the CCGT power plant integrated with LNG regasification for the reference state x_0 and operation state x_1

	i	F_b ($x=x_0$)	P_b ($x=x_0$)	I_b ($x=x_0$)	F_b ($x=x_1$)	P_b ($x=x_1$)	I_b ($x=x_1$)
Gas Turbine (GT PRO)	2	146025.85	115464.88	30560.97	148978.00	117735.71	31242.29
Fuel Compressor	3	3846.00	2555.16	1290.84	3925.00	2607.29	1317.71
Pipe (PCE)	6	17814.30	17743.23	71.07	18176.49	18103.97	72.51
ST 1: ST Group	7	6949.64	6019.00	930.64	6982.79	5843.00	1139.79
ST 1: ST Group	8	11155.12	9860.00	1295.12	10356.93	9250.00	1106.93
Mixer	9	14953.97	14954.09	-0.12	15325.36	15324.74	0.61
Pipe (PCE)	10	4203.27	4160.37	42.90	4247.53	4204.18	43.35
General Condenser	11	3688.90	755.35	4444.25	4824.92	784.45	5609.36
Pipe (PCE)	12	11826.66	11819.71	6.96	11153.42	11146.86	6.56
Pipe (PCE)	13	3393.47	3391.48	2.00	3322.94	3320.99	1.95
Pump (PCE)	16	9.84	1.90	7.93	9.88	2.00	7.88
HRSG 1: Duct - GT to Horizontal HRSG	17	59826.88	59541.84	285.04	60792.71	60503.38	289.32
HRSG 1: Superheater (PCE)	18	1577.32	1444.20	133.12	1612.69	1473.56	139.13
HRSG 1: Superheater (PCE)	19	1892.84	1534.76	358.07	1921.86	1565.96	355.90
HRSG 1: Evaporator (PCE)	20	13393.31	11352.98	2040.32	13681.31	11587.13	2094.19
Splitter	21	15192.82	15197.51	-4.69	15505.61	15504.60	1.01
HRSG 1: Economiser (PCE)	22	976.94	894.19	82.75	1007.50	912.50	95.00
HRSG 1: Superheater (PCE)	23	139.07	85.89	53.19	140.99	86.79	54.20
HRSG 1: Economiser (PCE)	24	1771.45	1447.70	323.75	1811.45	1477.36	334.09
HRSG 1: Evaporator (PCE)	25	4375.48	3592.30	783.18	4413.38	3630.15	783.23
HRSG 1: Economiser (PCE)	26	937.26	783.99	153.27	956.25	797.88	158.37
Splitter	27	1970.66	1971.08	-0.42	2005.56	2006.20	-0.63
HRSG 1: Economiser (PCE)	28	1509.99	847.06	662.93	1449.91	831.46	618.44
Pump (PCE)	30	77.24	51.95	25.29	78.78	53.01	25.77
Pump (PCE)	31	12.48	5.13	7.35	12.69	5.22	7.47
Deaerator	32	1321.52	1181.54	139.98	1344.28	1202.47	141.82
Makeup / Blowdown	34	112.25	112.29	-0.04	145.18	145.18	0.01
Refrigerant Turbine	35	7176.19	5235.38	1940.81	7452.65	5435.34	2017.31
Refrigerant Pump	36	28.38	10.68	17.70	30.34	11.09	19.25
General HX-SS	37	11913.65	7920.87	3992.78	11809.35	8226.01	3583.34
Fuel Pump	40	6968.00	1553.48	5414.52	7434.00	1239.26	6194.74
General HX-SS	41	14777.88	3423.82	18201.69	14567.97	3228.91	17796.88
Fuel Turbine	42	5962.98	4419.00	1543.98	5972.75	4249.00	1723.75
General HX-SS	43	982.41	264.79	717.62	961.99	255.03	706.96
Brine Pump	46	15.04	6.95	8.09	14.20	6.55	7.65
Brine Pump	49	4.47	1.99	2.48	4.38	1.95	2.43
Generator 1	51	55638.00	54785.00	853.00	56943.00	56073.00	870.00
Generator 2	52	15879.00	15440.00	439.00	15093.00	14670.00	423.00
Generator 3	53	5207.00	5030.00	177.00	5405.00	5223.00	182.00
Generator 4	54	4419.00	4264.00	155.00	4249.00	4099.00	150.00

B5

Values of exergy efficiency and specific consumption of exergy for individual components of CCGT plant integrated with LNG regasification in the for the reference state x_0 and operation state x_1

	i	ηB x=x_0	kB x=x_0	ηB x=x_1	kB x=x_1
Gas Turbine (GT PRO)	2	0.79	1.265	0.79	1.27
Fuel Compressor	3	0.66	1.505	0.66	1.51
Pipe (PCE)	6	1.00	1.004	1.00	1.00
ST 1: ST Group	7	0.87	1.155	0.84	1.20
ST 1: ST Group	8	0.88	1.131	0.89	1.12
Mixer	9	1.00	1.000	1.00	1.00
Pipe (PCE)	10	0.99	1.010	0.99	1.01
General Condenser	11	0.20	4.884	0.16	6.15
Pipe (PCE)	12	1.00	1.001	1.00	1.00
Pipe (PCE)	13	1.00	1.001	1.00	1.00
Pump (PCE)	16	0.19	5.168	0.20	4.94
HRSG 1: Duct - GT to Horizontal HRSG	17	1.00	1.005	1.00	1.00
HRSG 1: Superheater (PCE)	18	0.92	1.092	0.91	1.09
HRSG 1: Superheater (PCE)	19	0.81	1.233	0.81	1.23
HRSG 1: Evaporator (PCE)	20	0.85	1.180	0.85	1.18
Splitter	21	1.00	1.000	1.00	1.00
HRSG 1: Economiser (PCE)	22	0.92	1.093	0.91	1.10
HRSG 1: Superheater (PCE)	23	0.62	1.619	0.62	1.62
HRSG 1: Economiser (PCE)	24	0.82	1.224	0.82	1.23
HRSG 1: Evaporator (PCE)	25	0.82	1.218	0.82	1.22
HRSG 1: Economiser (PCE)	26	0.84	1.195	0.83	1.20
Splitter	27	1.00	1.000	1.00	1.00
HRSG 1: Economiser (PCE)	28	0.56	1.783	0.57	1.74
Pump (PCE)	30	0.67	1.487	0.67	1.49
Pump (PCE)	31	0.41	2.434	0.41	2.43
Deaerator	32	0.89	1.118	0.89	1.12
Makeup / Blowdown	34	1.00	1.000	1.00	1.00
Refrigerant Turbine	35	0.73	1.371	0.73	1.37
Refrigerant Pump	36	0.38	2.658	0.37	2.74
General HX-SS	37	0.66	1.504	0.70	1.44
Fuel Pump	40	0.22	4.485	0.17	6.00
General HX-SS	41	0.23	4.316	0.22	4.51
Fuel Turbine	42	0.74	1.349	0.71	1.41
General HX-SS	43	0.27	3.710	0.27	3.77
Brine Pump	46	0.46	2.165	0.46	2.17
Brine Pump	49	0.45	2.242	0.45	2.24
Generator 1	51	0.98	1.016	0.98	1.02
Generator 2	52	0.97	1.028	0.97	1.03
Generator 3	53	0.97	1.035	0.97	1.03
Generator 4	54	0.96	1.036	0.96	1.04

B6

Values of exergy, exergy costs and specific exergy costs for all streams of CCGT plant integrated with LNG regasification for reference statate x_0

j	Stream	B*	B	kj*
1	Air	3067.54	3067.54	1.00
2	Fuel	145266.17	142796.75	1.02
3	Fuel	140241.59	140241.59	1.00
4	Water	29.56	29.56	1.00
5	Steam	27821.11	17743.23	1.57
6	Steam	16924.19	10793.59	1.57
7	Steam	6887.63	4160.37	1.66
8	Steam	23811.82	14954.09	1.59
9	Steam	6049.20	3798.97	1.59
10	Ammonia	31616.12	11947.98	2.65
11	Ammonia	25742.18	12703.33	2.03
12	Bine	31407.26	11826.66	2.66
13	Bine	31407.26	11819.71	2.66
14	Water	175.26	110.07	1.59
15	Flue Gas	76962.18	59541.84	1.29
16	Flue Gas	74923.38	57964.52	1.29
17	Steam	25782.32	16370.10	1.57
18	Flue Gas	72476.75	56071.68	1.29
19	Steam	23905.37	15192.82	1.57
20	Steam	23335.69	14835.34	1.57
21	Flue Gas	55164.92	42678.38	1.29
22	Water/Steam	6593.54	3839.83	1.72
23	Flue Gas	53902.16	41701.43	1.29
24	Flue Gas	53722.39	41562.36	1.29
25	Water/Steam	5330.78	2945.65	1.81
26	Flue Gas	51432.66	39790.91	1.29
27	Steam	6707.87	4117.39	1.63
28	Flue Gas	45777.03	35415.43	1.29
29	Water	3949.91	1970.66	2.00
30	Water	1052.23	525.09	2.00
31	Flue Gas	44565.56	34478.17	1.29
32	Flue Gas	42613.78	32968.18	1.29
33	Water	3041.04	1497.94	2.03
34	Water	2738.43	1186.67	2.31
35	Water	2145.58	959.35	2.24
36	Steam	569.69	362.17	1.57
37	Water	193.81	112.29	1.73
38	Flue Gas	76962.18	59826.88	1.29
39	Water	2897.67	1446.00	2.00
40	Water	2715.27	1181.54	2.30
41	Steam	27821.11	17814.30	1.56
42	Steam	6887.63	4203.27	1.64
43	Water	193.52	111.97	1.73
44	Make-up water	0.28	0.28	1.00
45	Ammonia	12626.85	4771.79	2.65
46	Ammonia	25639.24	12692.66	2.02
48	LNG	121845.59	121845.59	1.00
49	LNG	134779.51	123399.07	1.09
50	LNG	121767.12	111485.41	1.09
51	LNG	105626.36	96707.54	1.09
52	LNG	99113.44	90744.56	1.09
53	LNG	98129.95	90479.77	1.08
54	Brine	15243.53	15243.53	1.00
55	Brine	15266.50	15250.48	1.00
56	Brine	3397.22	3393.47	1.00
57	Brine	4373.89	4373.89	1.00
58	Brine	4380.72	4375.88	1.00
59	Brine	3397.22	3391.48	1.00
60	Shaft power to G1	71573.54	55638.00	1.29
61	Heat from G1	1.31	1.00	1.31
62	Net electricity from G1	66376.51	50807.00	1.31
63	Power to Fuel Compressor	5024.58	3846.00	1.31
64	Power to GT aux	172.45	132.00	1.31
65	ST case 2 shaft power	10896.92	6019.00	1.81
66	ST case 1 shaft power	17762.61	9860.00	1.80
67	Heat from G2	1.86	1.00	1.86
68	Net electricity from G2	15540.82	8372.44	1.86
69	Power to LNG pump	12933.92	6968.00	1.86
70	Power to Pump 16	18.26	9.84	1.86
71	Power to Pump 30	143.37	77.24	1.86
72	Power to Pump 31	23.17	12.48	1.86
73	Shaft power to ammonia pump	102.94	28.38	3.63
74	Shaft power to G3	18886.33	5207.00	3.63
75	Heat from G3	3.75	1.00	3.75
76	Net electricity from G3	18886.33	5030.00	3.75
77	Shaft power to G4	6512.91	4419.00	1.47
78	Heat from G4	1.53	1.00	1.53
79	Net electricity from G4	6483.11	4244.49	1.53
80	Power to Pump 46	22.97	15.04	1.53
81	Power to Pump 49	6.83	4.47	1.53

B7

Values of exergy, exergy costs and specific exergy costs for all streams of CCGT plant integrated with LNG regasification for operational state x_1

j	Stream	B*	B	kj*
1	Air	3105.28	3105.28	1.00
2	Fuel	148233.01	145709.91	1.02
3	Fuel	143102.62	143102.62	1.00
4	Water	30.80	30.80	1.00
5	Steam	28392.38	18103.97	1.57
6	Steam	17441.30	11121.18	1.57
7	Steam	6937.49	4204.18	1.65
8	Steam	24378.79	15324.74	1.59
9	Steam	7902.86	4967.82	1.59
10	Ammonia	34656.99	12408.27	2.79
11	Ammonia	26981.46	13192.72	2.05
12	Bine	30464.89	11153.42	2.73
13	Bine	30464.89	11146.86	2.73
14	Water	227.33	142.90	1.59
15	Flue Gas	78248.36	60503.38	1.29
16	Flue Gas	76162.68	58890.69	1.29
17	Steam	26306.71	16702.93	1.57
18	Flue Gas	73677.16	56968.83	1.29
19	Steam	24399.75	15505.61	1.57
20	Steam	23821.18	15136.96	1.57
21	Flue Gas	55983.26	43287.51	1.29
22	Water/Steam	6705.85	3918.48	1.71
23	Flue Gas	54680.27	42280.01	1.29
24	Flue Gas	54497.93	42139.02	1.29
25	Water/Steam	5402.86	3005.98	1.80
26	Flue Gas	52155.21	40327.57	1.29
27	Steam	6755.15	4160.74	1.62
28	Flue Gas	46447.43	35914.19	1.29
29	Water	3960.22	2005.56	1.97
30	Water	1047.37	530.59	1.97
31	Flue Gas	45210.72	34957.94	1.29
32	Flue Gas	43335.58	33508.04	1.29
33	Water	3060.14	1528.62	2.00
34	Water	2723.52	1207.68	2.26
35	Water	2121.23	976.64	2.17
36	Steam	578.56	367.64	1.57
37	Water	246.08	145.18	1.70
38	Flue Gas	78248.36	60792.71	1.29
39	Water	2912.85	1475.61	1.97
40	Water	2699.80	1202.47	2.25
41	Steam	28392.38	18176.49	1.56
42	Steam	6937.49	4247.53	1.63
43	Water	245.80	144.90	1.70
44	Make-up water	0.28	0.28	1.00
45	Ammonia	13841.32	4955.62	2.79
46	Ammonia	26865.26	13181.63	2.04
48	LNG	121845.59	121845.59	1.00
49	LNG	135744.19	123084.86	1.10
50	LNG	122720.24	111275.51	1.10
51	LNG	106653.95	96707.54	1.10
52	LNG	100066.91	90734.79	1.10
53	LNG	99103.77	90479.77	1.10
54	Brine	14375.78	14375.78	1.00
55	Brine	14398.60	14382.33	1.00
56	Brine	3326.89	3322.94	1.00
57	Brine	4282.98	4282.98	1.00
58	Brine	4290.02	4284.93	1.00
59	Brine	3326.89	3320.99	1.00
60	Shaft power to G1	73293.27	56943.00	1.29
61	Heat from G1	1.31	1.00	1.31
62	Net electricity from G1	67990.35	52016.00	1.31
63	Power to Fuel Compressor	5130.39	3925.00	1.31
64	Power to GT aux	172.54	132.00	1.31
65	ST case 2 shaft power	10951.09	5843.00	1.87
66	ST case 1 shaft power	16475.93	9250.00	1.78
67	Heat from G2	1.87	1.00	1.87
68	Net electricity from G2	13338.93	7134.65	1.87
69	Power to LNG pump	13898.60	7434.00	1.87
70	Power to Pump 16	18.47	9.88	1.87
71	Power to Pump 30	147.29	78.78	1.87
72	Power to Pump 31	23.73	12.69	1.87
73	Shaft power to ammonia pump	116.19	30.34	3.83
74	Shaft power to G3	20699.48	5405.00	3.83
75	Heat from G3	3.96	1.00	3.96
76	Net electricity from G3	20699.48	5223.00	3.96
77	Shaft power to G4	6587.05	4249.00	1.55
78	Heat from G4	1.61	1.00	1.61
79	Net electricity from G4	6557.19	4080.42	1.61
80	Power to Pump 46	22.82	14.20	1.61
81	Power to Pump 49	7.04	4.38	1.61

B8

The values of streams, cumulative stream values and exergy costs of fuels and products of individual components of CCGT plant integrated with LNG regasification for the reference state x_0.

i	Component	F	F*	kF*	P	P*	kP*	k	k
2	**Gas Turbine (GT PRO)**	146025.85	148535.72	1.02	115464.88	148535.72	1.29	1.26	1.26
3	**Fuel Compressor**	3846.00	5024.58	1.31	2555.16	5024.58	1.97	1.51	1.51
6	**Pipe (PCE)**	17814.30	27821.11	1.56	17743.23	27821.11	1.57	1.00	1.00
7	**ST 1: ST Group**	6949.64	10896.92	1.57	6019.00	10896.92	1.81	1.15	1.15
8	**ST 1: ST Group**	11155.12	17762.61	1.59	9860.00	17762.61	1.80	1.13	1.13
9	**Mixer**	14953.97	23811.82	1.59	14954.09	23811.82	1.59	1.00	1.00
10	**Pipe (PCE)**	4203.27	6887.63	1.64	4160.37	6887.63	1.66	1.01	1.01
11	**General Condenser**	3688.90	5873.94	1.59	755.35	5873.94	7.78	4.88	4.88
12	**Pipe (PCE)**	11826.66	31407.26	2.66	11819.71	31407.26	2.66	1.00	1.00
13	**Pipe (PCE)**	3393.47	3397.22	1.00	3391.48	3397.22	1.00	1.00	1.00
16	**Pump (PCE)**	9.84	18.26	1.86	1.90	18.26	9.59	5.17	5.17
17	**HRSG 1: Duct - GT to Horizontal HRSG**	59826.88	76962.18	1.29	59541.84	76962.18	1.29	1.00	1.00
18	**HRSG 1: Superheater (PCE)**	1577.32	2038.80	1.29	1444.20	2038.80	1.41	1.09	1.09
19	**HRSG 1: Superheater (PCE)**	1892.84	2446.63	1.29	1534.76	2446.63	1.59	1.23	1.23
20	**HRSG 1: Evaporator (PCE)**	13393.31	17311.83	1.29	11352.98	17311.83	1.52	1.18	1.18
21	**Splitter**	15192.82	23905.37	1.57	15197.51	23905.37	1.57	1.00	1.00
22	**HRSG 1: Economiser (PCE)**	976.94	1262.77	1.29	894.19	1262.77	1.41	1.09	1.09
23	**HRSG 1: Superheater (PCE)**	139.07	179.76	1.29	85.89	179.76	2.09	1.62	1.62
24	**HRSG 1: Economiser (PCE)**	1771.45	2289.73	1.29	1447.70	2289.73	1.58	1.22	1.22
25	**HRSG 1: Evaporator (PCE)**	4375.48	5655.63	1.29	3592.30	5655.63	1.57	1.22	1.22
26	**HRSG 1: Economiser (PCE)**	937.26	1211.47	1.29	783.99	1211.47	1.55	1.20	1.20
27	**Splitter**	1970.66	3949.91	2.00	1971.08	3949.91	2.00	1.00	1.00
28	**HRSG 1: Economiser (PCE)**	1509.99	1951.77	1.29	847.06	1951.77	2.30	1.78	1.78
30	**Pump (PCE)**	77.24	143.37	1.86	51.95	143.37	2.76	1.49	1.49
31	**Pump (PCE)**	12.48	23.17	1.86	5.13	23.17	4.52	2.43	2.43
32	**Deaerator**	1321.52	2715.27	2.05	1181.54	2715.27	2.30	1.12	1.12
34	**Makeup / Blowdown**	112.25	193.81	1.73	112.29	193.81	1.73	1.00	1.00
35	**Refrigerant Turbine**	7176.19	18989.27	2.65	5235.38	18989.27	3.63	1.37	1.37
36	**Refrigerant Pump**	28.38	102.94	3.63	10.68	102.94	9.64	2.66	2.66
37	**General HX-SS**	11913.65	13012.39	1.09	7920.87	13012.39	1.64	1.50	1.50
40	**Fuel Pump**	6968.00	12933.92	1.86	1553.48	12933.92	8.33	4.49	4.49
41	**General HX-SS**	14777.88	16140.76	1.09	3423.82	16140.76	4.71	4.32	4.32
42	**Fuel Turbine**	5962.98	6512.91	1.09	4419.00	6512.91	1.47	1.35	1.35
43	**General HX-SS**	982.41	983.50	1.00	264.79	983.50	3.71	3.71	3.71
46	**Brine Pump**	15.04	22.97	1.53	6.95	22.97	3.31	2.16	2.16
49	**Brine Pump**	4.47	6.83	1.53	1.99	6.83	3.42	2.24	2.24
51	**Generator 1**	55638.00	71573.54	1.29	54785.00	71573.54	1.31	1.02	1.02
52	**Generator 2**	15879.00	28659.54	1.80	15440.00	28659.54	1.86	1.03	1.03
53	**Generator 3**	5207.00	18886.33	3.63	5030.00	18886.33	3.75	1.04	1.04
54	**Generator 4**	4419.00	6512.91	1.47	4264.00	6512.91	1.53	1.04	1.04

B9

The values of streams, cumulative stream values and exergy costs of fuels and products of individual components of CCGT plant integrated with LNG regasification for the operational state x_1.

i	Component	F	F*	kF*	P	P*	kP*	k	k
2	**Gas Turbine (GT PRO)**	148978.00	151541.63	1.02	117735.71	151541.63	1.29	1.27	1.27
3	**Fuel Compressor**	3925.00	5130.39	1.31	2607.29	5130.39	1.97	1.51	1.51
6	**Pipe (PCE)**	18176.49	28392.38	1.56	18103.97	28392.38	1.57	1.00	1.00
7	**ST 1: ST Group**	6982.79	10951.09	1.57	5843.00	10951.09	1.87	1.20	1.20
8	**ST 1: ST Group**	10356.93	16475.93	1.59	9250.00	16475.93	1.78	1.12	1.12
9	**Mixer**	15325.36	24378.79	1.59	15324.74	24378.79	1.59	1.00	1.00
10	**Pipe (PCE)**	4247.53	6937.49	1.63	4204.18	6937.49	1.65	1.01	1.01
11	**General Condenser**	4824.92	7675.54	1.59	784.45	7675.54	9.78	6.15	6.15
12	**Pipe (PCE)**	11153.42	30464.89	2.73	11146.86	30464.89	2.73	1.00	1.00
13	**Pipe (PCE)**	3322.94	3326.89	1.00	3320.99	3326.89	1.00	1.00	1.00
16	**Pump (PCE)**	9.88	18.47	1.87	2.00	18.47	9.24	4.94	4.94
17	**HRSG 1: Duct - GT to Horizontal HRSG**	60792.71	78248.36	1.29	60503.38	78248.36	1.29	1.00	1.00
18	**HRSG 1: Superheater (PCE)**	1612.69	2085.68	1.29	1473.56	2085.68	1.42	1.09	1.09
19	**HRSG 1: Superheater (PCE)**	1921.86	2485.53	1.29	1565.96	2485.53	1.59	1.23	1.23
20	**HRSG 1: Evaporator (PCE)**	13681.31	17693.89	1.29	11587.13	17693.89	1.53	1.18	1.18
21	**Splitter**	15505.61	24399.75	1.57	15504.60	24399.75	1.57	1.00	1.00
22	**HRSG 1: Economiser (PCE)**	1007.50	1302.99	1.29	912.50	1302.99	1.43	1.10	1.10
23	**HRSG 1: Superheater (PCE)**	140.99	182.34	1.29	86.79	182.34	2.10	1.62	1.62
24	**HRSG 1: Economiser (PCE)**	1811.45	2342.72	1.29	1477.36	2342.72	1.59	1.23	1.23
25	**HRSG 1: Evaporator (PCE)**	4413.38	5707.78	1.29	3630.15	5707.78	1.57	1.22	1.22
26	**HRSG 1: Economiser (PCE)**	956.25	1236.70	1.29	797.88	1236.70	1.55	1.20	1.20
27	**Splitter**	2005.56	3960.22	1.97	2006.20	3960.22	1.97	1.00	1.00
28	**HRSG 1: Economiser (PCE)**	1449.91	1875.15	1.29	831.46	1875.15	2.26	1.74	1.74
30	**Pump (PCE)**	78.78	147.29	1.87	53.01	147.29	2.78	1.49	1.49
31	**Pump (PCE)**	12.69	23.73	1.87	5.22	23.73	4.55	2.43	2.43
32	**Deaerator**	1344.28	2699.80	2.01	1202.47	2699.80	2.25	1.12	1.12
34	**Makeup / Blowdown**	145.18	246.08	1.69	145.18	246.08	1.70	1.00	1.00
35	**Refrigerant Turbine**	7452.65	20815.67	2.79	5435.34	20815.67	3.83	1.37	1.37
36	**Refrigerant Pump**	30.34	116.19	3.83	11.09	116.19	10.48	2.74	2.74
37	**General HX-SS**	11809.35	13023.94	1.10	8226.01	13023.94	1.58	1.44	1.44
40	**Fuel Pump**	7434.00	13898.60	1.87	1239.26	13898.60	11.22	6.00	6.00
41	**General HX-SS**	14567.97	16066.29	1.10	3228.91	16066.29	4.98	4.51	4.51
42	**Fuel Turbine**	5972.75	6587.05	1.10	4249.00	6587.05	1.55	1.41	1.41
43	**General HX-SS**	961.99	963.13	1.00	255.03	963.13	3.78	3.77	3.77
46	**Brine Pump**	14.20	22.82	1.61	6.55	22.82	3.48	2.17	2.17
49	**Brine Pump**	4.38	7.04	1.61	1.95	7.04	3.61	2.24	2.24
51	**Generator 1**	56943.00	73293.27	1.29	56073.00	73293.27	1.31	1.02	1.02
52	**Generator 2**	15093.00	27427.01	1.82	14670.00	27427.01	1.87	1.03	1.03
53	**Generator 3**	5405.00	20699.48	3.83	5223.00	20699.48	3.96	1.03	1.03
54	**Generator 4**	4249.00	6587.05	1.55	4099.00	6587.05	1.61	1.04	1.04