Volume 7, Issue 2, December 2021 - ISSN 2356-8569

مركز الأكاديمية للنشر
ACADEMY Publishing Center

Journal of Renewable Energy and Sustainable Development

RESD

Academy Publishing Center
Journal of Renewable Energy and Sustainable Development (RESD)

ACADEMY Publishing Center

RESD
Volume 7, Issue 2, December 2021
ISSN: 2356-8518 Print Version
ISSN: 2356-8569 Online Version

http://apc.aast.edu

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RESD Journal of Renewable Energy and Sustainable Development

Renewable Energy and Sustainable Development (RESD) is a biannual international peer-reviewed journal, which presents a global forum for dissemination of research articles, case studies and reviews focusing on all aspects of renewable energy and its role in sustainable development. The topics of focal interest to RESD include, but are not limited to, all aspects of wind energy, wave/tidal energy, solar energy, as well as energy from biomass and biofuel. The integration of renewable energy technologies in electrical power networks and smart grids is another topic of interest to RESD. Experimental, computational and theoretical studies are all welcomed to RESD.

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http://dx.doi.org/10.21622/RESD.2021.07.2.041

Mission Possible - The Mission on Climate Neutral and Smart Cities A new approach to sustainable urban transformation and urban transition to climate neutrality

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Europe is taking the lead in the urban transition to climate neutrality to strengthen its role as a global driver of sustainable growth, creating synergies between European and international climate initiatives and stakeholders.

The Mission on Climate Neutral and Smart Cities is a challenging and ambitious endeavour where cities commit to a new form of sustainable urban transformation for the benefit of quality of life and sustainability.

The European Green Deal announced by the European Commission will transform the EU into a modern resource efficient and competitive economy and is the strategy through which to achieve EU climate neutrality by 2050. Cities have the potential to lead the efforts to deliver on the European Green Deal, because they produce about 72% of all global greenhouse gas emissions although cities cover about 3% of the land on Earth. Moreover, cities are growing fast and in Europe, it is estimated that by 2050 almost 85% of Europeans will be living in cities.

Therefore, the climate emergency must be tackled by cities and by citizens. This is the rationale behind the work of the EU Mission Board on Climate Neutral Cities and after consultations with citizens all over Europe the Mission Board proposes the following mission:

"100 climate neutral cities by 2030 - by and for the citizens".

The main objective of the proposed Mission is to support, promote and showcase 100 European cities in their systemic transformation towards climate neutrality by 2030. The mission would make these cities into experimentation and innovation hubs for all cities, thus leading on the delivery of the European Green Deal and on Europe's efforts to become climate neutral by 2050.
To achieve in ten years what Europe plans to achieve in 30 years is a huge challenge that requires a systemic transformation of European cities. This is urgent and necessary for acting on the global climate emergency and for delivering co-benefits that will create better jobs and enhance people's well-being. It is also feasible with the availability of technologies and innovative solutions for sustainable energy, transport, food, water and material systems.

Climate neutrality is achieved by reducing greenhouse gas emissions as much as possible and compensating for any remaining emissions. The transition to a net-zero emissions society requires action on all fronts such as; energy, transport, mobility, buildings, and shifting towards greener, digital and circular economies.

The Mission considers and deals with the international dimension as climate neutrality is a global problem that requires international dialogue and cooperation. Although the focus is on the intra-European content and setup of the mission, the issue of the international outreach of the mission is considered a priority, to facilitate and create synergies between European and international climate initiatives and stakeholders – academia, business and citizens.

The international dimension of the Mission is also characterised by its contribution to the UN Agenda 2030 for Sustainable Development that provides a global policy framework for ending all forms of poverty, fighting inequalities and tackling climate change in a socially inclusive manner.

A holistic and transformative mission for climate neutral cities, based on citizen participation and social inclusiveness, can contribute and help EU progress towards multiple Sustainable Development Goals (SDGs). The approach to cities' climate-related challenges is at the core of SDG 11 - "Sustainable Cities and Communities" and contributes significantly to other SDGs such as "Good Health and Well-Being",

 Volume 7, Issue 2, December 2021 - ISSN 2356-8569
http://dx.doi.org/10.21622/RESD.2021.07.2.041

"Decent Work and Economic Growth" and "Affordable and Clean Energy". In this respect and as energy production and use is currently responsible for 75% of EU greenhouse gas emissions, energy consumption in all its forms needs to be reduced, especially in urban areas where consumption is highest.

Cities are encouraged to connect to international networks in order to accelerate learning, replicability and scaling-up of solutions through sharing of good practices and joint actions and ultimately serve as an inspiration for cities across the world.

References

REPORT 100 Climate-neutral Cities by 2030 – by and for the Citizens https://ec.europa.eu/info/publications/100-climate-neutral-cities-2030-and-citizens_en

About Chrysses Nicolaides

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Chrysses is a Senior Consultant, Member of the EU Mission Board on Climate Neutral and Smart Cities, Managing partner of CNE Business Development Ltd and founder and coordinator of the Smart Cities Mediterranean Cluster (SMART-MED).

He has over 30 years of global experience working in senior positions for companies and multinational organizations, providing strategic, business, operations, administrative and technical leadership.

Since 2002, Chrysses is actively involved with the design and development of projects relating to the European strategy for smart, sustainable and inclusive growth.

In May 2014, he founded the "Smart Cities Mediterranean Cluster" involving over 120 multidisciplinary organizations and the focus is in the area of Smart Cities and Blue growth with projects and initiatives to tackle related global challenges and foster innovation in energy, transport, ICT, climate change and the environment. The emphasis is in linking research and industry to develop and implement solutions with the involvement of Government departments, local authorities, SME's, and other stakeholders, for the benefit of society and citizens.

Chrysses holds a Bachelor of Science degree with Honours obtained at the Polytechnic of Central London (University of Westminster) in 1978 in the UK.

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Journal of Renewable Energy and Sustainable Development (RESD) Volume 7, Issue 2, December 2021 - ISSN 2356-8569
http://dx.doi.org/10.21622/RESD.2021.07.2.043

Received on, 25 May 2021 Accepted on, 15 July 2021 Published on, 10 November 2021

ANALYSIS OF THE ECONOMIC VIABILITY OF THE INSTALLATION OF A PHOTOVOLTAIC SYSTEM AT JORGE DE ABREU REGIONAL HOSPITAL IN SINOP-MT

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ABSTRACT

Brazilian consumers have the possibility to produce their own energy using renewable sources or qualified cogeneration and even provide the surplus for the distribution network of their locality, as determined by Normative Resolution no. 482/2012 issued by the National Electric Energy Agency (ANEEL). In view of this, the use of photovoltaic systems for electricity generation has grown surprisingly reaching the mark of 8 gigawatts of installed power on Brazilian soil in the year 2021 [1]. In Brazil, public agencies represent 0.1% with 4.7MW installed [1], and 0.38% in the state of Mato Grosso [14]. Thus, aiming at the rise of electricity generation in public buildings due to the possibility of reducing the electric bill costs, the present work deals with the dimensioning, budget quotation and economic feasibility analysis regarding the installation of a grid-connected photovoltaic power generation system to meet the energy demands of Jorge de Abreu Regional Hospital in the city of Sinop, Mato Grosso state, Brazil. After carrying out the necessary research based on the techniques present in the economic sciences, as Minimum Attractiveness Rate (MRA), Net Present Value (NPV), Internal Rate of Return (IRR) and calculation of Payback, the present work considered a grid-connected solar energy generation system of 585 kW to supply the hospital's average monthly consumption of 93.829 kWh/month. The investment analysis showed that the project for the implementation of the photovoltaic system will have its NPV viable as of the 4th year of installation and the Payback (return on investment), observing the monetary corrections, of approximately four years and five months, thus configuring the system as economic financially.

Index terms: *Distributed generation, economic indicators, photovoltaic energy, renewable sources, sustainability.*

I. INTRODUCTION

Renewable energy sources are emerging technologies on the current world stage that have become a sustainable alternative for the production of electricity. It is estimated that renewable energies already occupy about 83% of the Brazilian energy matrix, according to the speech of the Secretary of Energy Planning and Development of the Ministry of Mines and Energy, Reive Barros [10]. Although energy sources that use fossil resources, such as oil, have large stocks, they are not renewable yet, not to mention the significant degradation of the environment they cause. Due to this, the sources with unlimited resources have been gaining prominence in the market, because in extension to the guarantee of not being resources that will be exhausted in nature, they are still relatively clean, decreasing the negative impacts to the environment.

One of the most widespread examples today is photovoltaic energy, which through a system of capturing solar rays through photovoltaic cells, is able to convert the irradiation collected into electric current by means of the so-called photovoltaic effect, thus supplying energy to the consumer unit in which it was installed. In this type of system, the energy produced can be connected to the network, configuring the system as ON-GRID, or it can be stored in stationary batteries, configuring the system as OFF-GRID [20]. In the system connected to the network, the conceived energy is lowered in the energy account and the surplus generation is converted into credits for the consumer, and can be used in up to 60 months, in an agreement with the contracted concessionaire, this is known as the system of "Solar Energy Credits" regulated by ANEEL (National Electric Energy Agency), for captive consumers who install this specie of system.

For the analysis of the viability of the installation of a photovoltaic system it was obtained as a basis researches in the municipality of Sinop, observing the enormous potential of the territory considering the incidence of solar rays which have an average of 5.00 kWh/m^2. day [7]. In this perspective, through review of previous works regarding solar energy in the city, it was also noted that the presence of photovoltaic systems is growing every day, however, only in the year 2019 there was a growth of 84% of all the facilities of the locality, not to mention the significant increase of 514,35% compared to the year 2018, thus making the market quite diversified and accessible [14].

Based on the aforementioned factors this structure was implemented in a public institution, namely the Jorge de Abreu Regional Hospital, which was inaugurated in December 2014 and is a reference for health in the region, serving as shelter for more than 430,000 people and having a large unit with care for several clinical sectors [11]. In this way, by reason of the large expenses that the hospital has to bear, the alternative of generating its own energy is an attractive option in terms of the reduction of expenses, since solar energy has an investment that returns after a certain period and that in this case, would return in a short time if compared to the years of operation of the entity.

Based on this assumption, the main objective is to analyze the feasibility of implementing a photovoltaic system in this building, the Jorge de Abreu de Sinop Regional Hospital, considering aspects such as the cost of projects, equipment and installation. In addition, there will be the use of definitions of economic studies such as NPV (Net Present Value), IRR (Internal Rate of Return) and Payback to prove the importance of the installation of the system.

II. LITERARY REVIEW

A. Photovoltaic System

Photovoltaic energy is the production of electrical energy through the capture of solar rays by means of a semiconductor material, more commonly silicon, which will establish the phenomenon of direct conversion of solar radiation into electric current, known as photovoltaic effect [5].

According to Castro [5], at present, this system can be used in a wide range of applications, for example in medium-power employment covering electrification in rural or remote regions without access to the distribution network, and dispersed productions connected to the network. As well as in low power applications ranging from clocks and calculators to road signs or parking meters.

The photovoltaic system can be subdivided into two categories: OFF-GRID and ON-GRID. The OFF-GRID type, most of the time, is adopted in locations that have no connection with the power utility, thus causing the need to use stationary batteries in the storage of the generated energy. In the ON-GRID type, there is no use of these batteries, which makes this system economically viable compared to the previous one, and in turn needs to be connected to the network. There are still hybrid photovoltaic systems, which supports integrating a battery-powered energy storage system at the same time that it is connected to the electrical grid. This ensures greater autonomy and security for the user, also aiming at the financial benefit in the acquisition of this infrastructure [5].

B. Analysis of Economic Viability

The analysis of economic viability is a process that encompasses several studies on the market and qualifies the effectiveness of an investment over a given time. To verify the efficiency of the installation of a photovoltaic system, some economic terms have been adopted which are listed in the subsequent sections, including the formulas presented, all taken from the digital practical guide "Financial Indicators for Investment Analysis" by author Renata Freitas de Camargo [4].

1) Minimum Attractiveness Rate: The acronym MRA, the minimum attractiveness rate, is a percentage that corresponds to the minimum that an investor proposes to earn, or the maximum that someone proposes to pay when making a loan. It is considered an excellent tool especially when choosing among the various investment options available. At both strategic and financial levels, MRA is one of the first tools to assess the attractiveness of an investment.

The investment analysis of MRA is estimated on the basis of the main interest rates practiced by the market, the researchers can mention for example those that currently have the most impact:

- TMF: Basic Financial Rate;
- TR: Reference rate;
- TJLP: Long-Term Interest Rate;
- SELIC: Special Settlement and Custody System

2) Net Present Value: Net Present Value (NPV) is an internationally accepted method by finance professionals and widely used to plan long-term investments as it is one of the best-known methods when dealing with analysis of the viability of investment projects [4]. The method consists of bringing to zero date all the cash flows of an investment project and adding them to the value of the initial investment, using as discount rate the Minimum Attractiveness Rate (MRA) of the company or project.

With the calculation of the Net Present Value, it is possible to make adjustments, discounting the interest rates to get the true notion of the value of money in the future. For this reason, the NPV not only compares

http://dx.doi.org/10.21622/RESD.2021.07.2.043

the investment with the expected return, but also takes into account the capital appreciation over time by calculating the real investment gain. The NPV formula is expressed as follows:

$$V_{PL} = \sum_{t=1}^{N} \frac{Fc_t}{(1+i)^n} \quad (01)$$

where, NPV is the Net Present Value, FC is the Cash Flow, t is the time when the cash flow occurred, i is the discount rate (or minimum attractiveness rate) and n = Time period.

For the analysis of the result obtained by calculating the NPV there are three possible situations:

- negative NPV: expenditure greater than revenue, that is, the project is unviable;
- positive NPV: revenue greater than expenditure, that is, the project is viable;
- NPV Zero = Income and expenditure are equal, that is, the decision to invest in the project is neutral.

3) Internal Rate of Return: The Internal Rate of Return also known as the IRR, is the rate that will equal the anticipated cash flow to the value of the investment. This rate is nothing more than an indicator, greatly used to assess the attractiveness of a project or investment. Its calculation is given by the formula described below:

$$VP = capital + \sum_{t=1}^{N} \frac{F_t}{(1+i)^t} \quad (02)$$

where, VP is the present value, Capital is the investment value, N is the Amount of periods, Ft is the Capital Inflow in period t and i is the Internal rate of return.

When the researchers analyze the IRR, they should compare it with the minimum attractiveness rate (MRA), because if its percentage is lower, the investment is economically unviable. Already if the IRR is larger than the MRA, the investment is considered viable.

4) Payback: The recovery time of the investment, or popularly known as Payback, is another risk indicator, being an important indicator within the investment decision-making process. It represents the number of periods necessary for the flow of benefits to exceed the invested capital.

Although it is a simple calculation, it is essential that all variables linked to the cash flow are analyzed for a correct execution of the Payback calculation, since the entered values and the discounted expenses must faithfully represent the planned scenario, so that it does not present unwanted surprises.

III. METHODOLOGY

This work addresses the analysis of the financial viability of the investment aiming at the installation of a photovoltaic power generation system to meet the consumption needs of the Regional Hospital of Sinop - MT. In a first moment the researchers will deal with the dimensioning of the photovoltaic system, the researchers will calculate the variables that directly impact the generation and they will carry out the quotation of the equipment, project and labor costs. After that, the researchers will perform the investment analysis to evaluate its implementation.

The two consumer units that serve the Jorge de Abreu de Sinop Regional Hospital were considered; the first one located at number 2799, avenue of Itaúbas, called Emergency Room, and the second unit located in Street of Caviúnas, without number, center, called Regional Hospital. Both units are three-phase, served on average voltage with a 127/220V secondary voltage lowering transformer and belonging to tariff group A.

For the preparation of this study, it is worth noting that some analyses could not be performed due to the location of the equipment installation not having been decided. In this sense, it is worth emphasizing that the resistance of the roof for the installation of the panels was not verified, the study of the coverage that allows the analysis of the interference of the shading throughout the year in the place of accommodation of the modules was not contemplated, and the calculations of losses by the voltage drop and heating of the inverter could not be calculated. For the purposes of carrying out the work, the researchers estimate, in comparison with other systems installed in the city of Sinop-MT, that the total losses of the solar energy plant will not exceed 10%, assuming a general efficiency of the system of 90%. Thus, the calculations presented should be reviewed and adjusted when the definition of points is solved and due technical studies are carried out.

A. Energy Consumption of the Jorge de Abreu de Sinop-MT Regional Hospital

Determining the consumer's energy consumption is fundamental to the design of the photovoltaic solar system. The consumption considered is the arithmetic average contained in the electric energy bills provided by the head of the financial department of the Jorge de Abreu Regional Hospital of the city of Sinop, Mato

 Volume 7, Issue 2, December 2021 - ISSN 2356-8569
http://dx.doi.org/10.21622/RESD.2021.07.2.043

Grosso. The analyzed period comprises from January to December 2020 and the mean value obtained was 93,829 kWh/month.

Consumption throughout the year showed oscillations mainly in the months of February to July in relation to the months of August to January. For this purpose, the standard deviation of consumption of 28.340kWh/month was determined in relation to the period observed. Given that the volume of energy demanded may vary according to the number of patients in need of services and the increased use of air conditioners in the excessive heat months of the region, it is not possible to present a linear consumption condition, justifying such a variation.

B. Dimensioning of the Photovoltaic System

The consumers of group A have hourly charges, that is, at certain hours the researchers call peak hours, when the electric system acts with greater intensity due to the high demand of industries and large trades, the cost of kWh consumed is higher. With a view on this, the researchers considered the methodology presented by Kikomoto [15] present in equations 3, 4 and 5, where they prioritize the reduction of the monthly demand for electric energy in the same period (end-to-end). If there are leftovers, this balance will be used to reduce consumption in the other tariff post, provided that it is conditioned to a correction of the value attributed by the adjustment factor, according to the formula below:

$$FA = \frac{TP}{TFP} \tag{03}$$

where, FA is the adjustment factor, TP is the fare on the end and TFP is the off-edge fare.

Therefore, the generation required is calculated in order to meet the need for injected energy for peak and off-peak periods, using the adjustment factor:

$$GN = CMFP + (FA * CMP) \tag{04}$$

where, GN is the generation needed, CMFP is the average off-peak consumption and CMP is the average consumption at the end.

From the solar radiation data of the region and the definition of the photovoltaic module, the researchers can determine with its characteristics the number of modules needed to generate customer consumption. Equation 5 shows as follows:

$$MN = \frac{GN}{IS \times AM \times EM \times ES \times DE} \tag{05}$$

where, IS is the average solar irradiation of the region, AM is the contact area of the photovoltaic module, EM is the percentage of efficiency of the photovoltaic module, ES is the efficiency of the generation system and DE the number of sunny days in the year.

In this way the system dimensioned to supply the energetic demands of the hospital requires a system composed of approximately 1,858 photovoltaic modules, resulting in a solar plant of 817.52 kWp of power generation. The budget quotation for the one that meets such needs was carried out next to the main supplier of equipment of this branch, according to the study of the company Greener, and the labor was quoted in the local trade. The final cost of the equipment is R$ 2,057,924.00 and labor of R$ 899,859.44. Totaling the amount of R$ 2,957,823.44.

It should also be noted that the quotation considered that the system will be installed on the roof of the building with fixing structures for trapezoidal metal tiles. The cost of adapting the current electrical infrastructure was not included in this study, because it would be necessary to have the prior definition of the places of installation of the equipment by the interested party.

C. Specification of the Equipment Considered

The present study took into consideration the system with the best cost that attended the dimensioning, conferred by the technical professional of the responsible area for the company where the quotation of the labor costs was accomplished, being indicated the set of equipments of 585 kW of power of invertors and 817,52 kWp of power of the photovoltaic modules, composed by:

- 7 three-phase solar photovoltaic inverters of the Growatt brand of nominal power of 75kW, model MAX75KTL3-LV, output voltage AC 220/380V, with 7 independent MPPTs and maximum DC input power of 112500W and efficiency of 98.3%;
- 1 three-phase solar photovoltaic inverter from Growatt, 60kW nominal power, model MAC60KTL3-LV, 220/380V AC output voltage, with 3 independent MPPTs and maximum DC input power of 90000W and efficiency of 98.5%;
- 1858 monocrystalline photovoltaic modules from Jinko brand composed by 120 cells, model JKM440M60HL4-V, with maximum power of 440W and efficiency of 20.39%.
- 3000 meters of Nexans 40023 Energyflex Afitox 0.6/1KV 1500V DC solar cable black.
- 3000 meters of Nexans 40023 Energyflex Afitox 0,6/1KV 1500V DC red solar cable.
- 240 Staubli MC4 Connector 320016P0001-UR PV-KBT4/6II-UR female coupler.
- 240 Staubli MC4 Connector 320016P0001-UR PV-

KBT4/6II-UR male coupler.
- 465 Solar structures Solar Romagnole 412012 2 pairs aluminium profile 240CM 4 modules T. metalic trapezoidal.

D. Maintenance Expenditures and Reduction in System Efficiency

According to Galdino [9], over the course of its system life some preventive maintenance is necessary to maintain the proper functioning of the system, this maintenance varies annually between 0.5 and 1% of the initial value of the structure. For the study of this research, the value of 1% was used.
The efficiency of photovoltaic modules varies according to their lifetime, this reduction in system performance varies between 0.5% and 1% per year [18]. The supplier brings together the technical data sheet of the product that its performance degradation is 2% in the first year and a linear decrease of 0.55% for the next 25 years.

E. Annual Average Readjustment Index of the Cost of Electricity

The adjustment of the annual electricity tariff is made according to the variation of the cost of purchasing energy, transport cost by high voltage lines, social charges, market inflation, operating costs and losses. Based on the data provided by the National Electric Energy Agency, the average readjustment in the last five years of the cost per kWh consumed in the State of Mato Grosso was approximately 8.32%, which the researchers will use in this work.

IV. RESULTS

According to the climatic data of the region, made available by CRESESB [7] the researchers can estimate the energy generated by the photovoltaic system and also taking into account the expenditures for maintenance, efficiency of panels and average annual readjustment of energy, and consequently the savings generated by this system.

An important factor to be observed in this case is that the consumer units of the Sinop Regional Hospital have contracted demand for electricity. When the power of the photovoltaic inverters is increased, this contract must be modified, since the sum of the nominal power of the inverters will be higher than the current one.

The tariff paid today by kWh hired by the consumer is R$ 19,26, and this value is affected by the annual average readjustment of the cost of electricity. The sum of the nominal power of the inverters is 585kW. Taking into account all the factors addressed in this research, according to Table I, the researchers can analyze the generation and savings forecast generated (without monetary correction) by the system over the first 5 years.

TABLE I
GENERATION FORECAST AND SAVINGS GENERAYED BY THE SYSTEM OVER THE INITIAL FIVE YEARS

Variables/Year	1st year	2nd year	3rd year	4th year	5th year
Performance of Panels (%)	100%	98%	97,5%	96,9%	96,4%
Annual Solar Generation (kWh/Year)	1.126.010,17	1.103.489,97	1.197.296,91	1.091.103,86	1.084.910,80
Average Energy Readjustment (%)	8,32%	8,32%	8,32%	8,32%	8,32%
Energy Cost (kWh/R$)	0,68	0,74	0,80	0,87	0,94
Cost of Maintenance (R$)	6.338,60	6.699,36	7.207,12	7.752,99	8.339,81
Cost of Demand Contracts (R$)	135.205,20	146.454,27	158.639,27	171,838,06	186.134,98
Economy Generated in the Year (R$)	627.521,15	663.236,50	713.504,42	767.545,84	825.640,70
Accumulated Economy (R$)	**627.521,15**	**1.290.757,64**	**2.004.262,06**	**2.771.807,90**	**3.597.448,60**

http://dx.doi.org/10.21622/RESD.2021.07.2.043

A. Analysis of the Economic Viability of the Investment

1) Minimum Attractiveness Rate: The Central Bank of Brazil (BACEN) [3] is the authority responsible for ensuring financial stability in Brazil, which confers power over the referenced interest rates traded in the country. The researchers will use the savings income index of the year 2020 of 2.11%, disclosed by BACEN, as reference to the minimum rate of attractiveness, becauseboth financial applications are considered low risk.

2) Net Present Value: From the rate defined in the previous item and using Equation 1 defined in this work, the researchers can determine the Net Present Value (VLP) of the financial investment. For this study the researchers considered the first 25 years of operation of the system because the manufacturer only informed the degradation rate for this period. Table II shows the discounted cash flow and its respective NPV for each year considered.

TABLE II
DISCOUNTED CASH FLOW AND CALCULATED NPV FOR EACH YEAR

Year	Discounted Cash Flow Year (R$)	Net Gift Value (R$)
1st year	614.554,06	-2.343.269,38
2nd year	636.109,47	-1.707.159,91
3rd year	670.180,58	-1.036.979,33
4th year	706.043,10	-330.936,23
5th year	743.788,10	412.852,71
6th year	783.514,50	1.196.367,20
7th year	825.320.98	2.021.688,19
8th year	869.314,57	2.891.002,76
9th year	915.606,66	3.806.609,42
10th year	964.314,10	4.770.923,51
11th year	1.015.559,46	5.786.482,97
12th year	1.069.471,29	6.855.954,26
13th year	1.126.184,38	7.982.138,64
14th year	1.185.840,05	9.167.978,69
15th year	1.248.586,45	10.416.565,14
16th year	1.314.578,88	11.731.144,02
17th year	1.383.980,08	13.115.124,10
18th year	1.456.960,59	14.572.084,69
19th year	1.533.699,08	16.105.783,77
20th year	1.614.382,71	17.720.166,48
21th year	1.699.207,52	19.419.374,00
22th year	1.788.378,78	21.207.752,78
23th year	1.882.111,49	23.089.864,22
24th year	1.980.630,49	25.070.494,71
25th year	2.084.171,44	27.154.666,14

In addition, in Figure 1, it is possible to observe graphically its performance over the 25 years covered in the study.

 Volume 7, Issue 2, December 2021 - ISSN 2356-8569
http://dx.doi.org/10.21622/RESD.2021.07.2.043

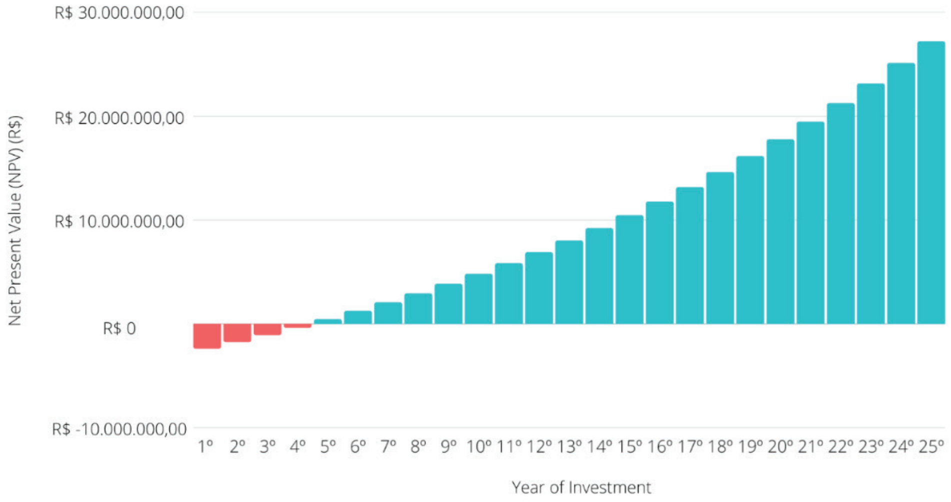

Fig. 1. NPV performance over the observed period.

3) Internal Rate of Return: The internal rate of return (IRR) was calculated for 5, 15 and 25 years of operation in order to perform a comparative. It was obtained respectively: 7% for the first five years, 27% for the initial 15 years of operation and 28% for the total period analyzed.

4) Payback: The Payback of the investment addressed has been calculated on the basis of the forecast cash inflows and discounted cash flow that takes into account the monetary correction of the inflows based on the benchmark rate. For the first case the researchers get the simple Payback of four years and three months. In the second case, the researchers take for analysis the discounted Payback with the value of four years and five months. In Figure 2, the researchers graphically analyze the behavior of Payback discounted over the analyzed period.

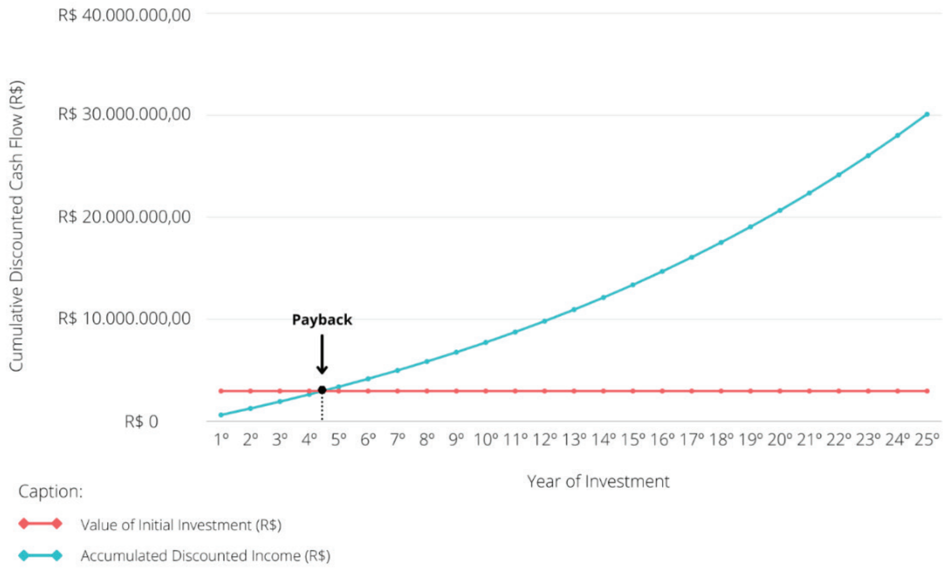

Fig. 2. Payback in relation to the initial investment and discounted cash flow.

V. DISCUSSION

Initially, the researchers can observe the high start cost required to install the system estimated at R$ 2,957,823.44, because of the high consumption present in the energy bills considered. However, when observing the expected calculation of generation and economy provided by the system, the impact is noted as the years evolve.

In the proposed financial viability analysis, by taking into account the Net Present Value (NPV), it can be seen that the investment has an unworkable return on investment in the first four years and is therefore considered viable. The internal rate of return (IRR), calculated for the three cases described, is analyzed as accessible, since all percentages are higher when compared to the minimum attractiveness rate (MRA) of 2.11%. The values of Payback portray the moment when the initial investment is recovered being in approximately four years and five months, that is, the exact moment when the investment will obtain financial return.

VI. CONCLUSION

Paying attention to the fact that the structure will be installed in a public building of social character and will be active for several years, it is understood that the installation of such a photovoltaic power generation system is viable and that in the long term its generated economy will make it possible to invest in other needs of the hospital, such as the acquisition of equipment and the opening of new medical treatment beds for the population.

The analyses carried out and the results obtained are based on the laws in force in the current Brazilian energy scenario, and any additional taxation will directly impact the data calculated for this study. One should also observe the dollar value (R$ 5.58 quotation of March 2021), because the equipment of a photovoltaic power generation system is imported and negotiated according to the import and export guidelines.

Moreover, it is left as a research suggestion, the technical analysis and implementation study of this system within the structural limitations of the Hospital Regional Jorge de Abreu, exploring the existing electrical installations, available area for installation of the panels and structural report, being possible as a result of this, to calculate in fact the losses by shading, voltage drop in the cabling and heating of the system.

Furthermore, other research can be carried out employing different methodologies to compare or complement the data obtained in this article, such as the levelized cost of energy (LCOE) which allows one to determine if one should go ahead with the project or as a means of comparing different strategies, and can be used for example to analyze the location of the installation of the photovoltaic modules on ground or roof structures.

VII. ACKNOWLEDGEMENTS

The researchers really appreciate the Mato Grosso Research Foundation for their support and encouragement in carrying out this research and the Secretary of State for Health of Mato Grosso for providing the necessary data.

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Journal of Renewable Energy and Sustainable Development (RESD) Volume 7, Issue 2, December 2021 - ISSN 2356-8569
http://dx.doi.org/10.21622/RESD.2021.07.2.052

Received on, 29 July 2021 Accepted on, 07 October 2021 Published on, 15 November 2021

Power-to-X / Electricity-to-Hydrogen in Sector Coupling An Overview & Case Studies

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ABSTRACT

Shifting from fossile-fuels to renewable energy has been strongly implemented globally in the past decades. However, this shifting process has been implemented through applying more wind and PV systems as a main energy sources. The afromentioned technologies are generating electricity as a direct product, however, it is realized that electricity demand is only 20% of the overall energy usage, while transportation demand and heat demand are occupying 30% and 50%, respectively. Thus the terms "electrification" and "Power-to-X" started to be commonly used and the focus has been deeply transitioned beyond electricity generation only.
This paper aims at exploring the contribution of high-temperature thermal storage to the optimization of hydrogen production as part of the Power-to-X business.

Keywords: Sector Coupling, PtX, e-fuel, Hydrogen, Green Transition, Thermal Energy Storage.

I. INTRODUCTION

During the past decades, the primary concern and focus has been on the generation of electricity, while the current focus has been moved towards storage and utilization of the excess generated electricity in order to cover the demand of heat as illustrated in Figure 1. In this respect, substantial focus has been put on the Power-to-X (PtX) technology. The present understanding is that excess electricity must be converted directly into hydrogen by installing electrolysis systems large enough to manage the peak power from the grid, thus offering grid balancing services. There is, however, an alternative where the balancing of the grid is done through installation of large high-temperature energy storages.

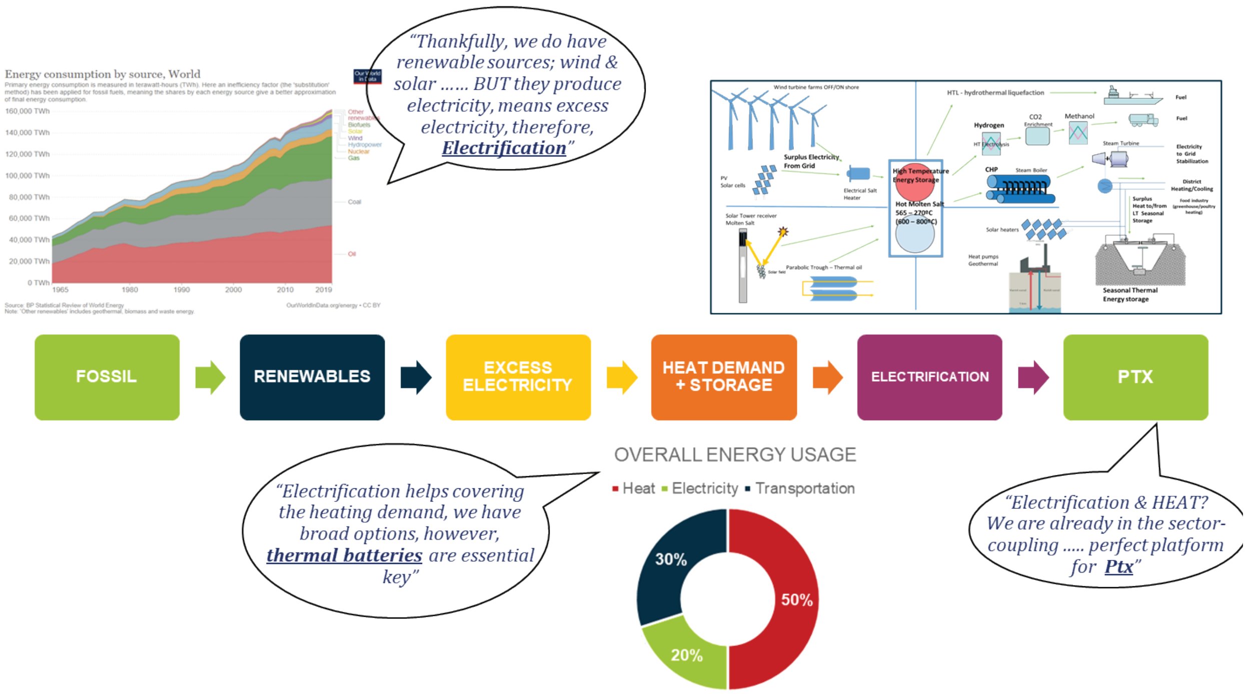

Fig. 1: Roadmap of transition from electricity generation towards PtX.

http://dx.doi.org/10.21622/RESD.2021.07.2.052

This paper discusses the role of Power-to-X-to-Power in different applications such as: 1) The retrofitting of Coal-fired Power Plants (CPP), 2) Synergy with Wind Energy business, and 3) Hydrogen and e-fuel production.
In order to validate the retrofitting concept, a proposed case of a potential CPP in Denmark with an average installed steam turbine generation (STG) capacity of 400 MWe is presented. In addition to the demonstration of how to apply the Power-to-X-to-Power concept to retrofit CPPs, the solution proposed also covers utilization of surplus energy generated from renewable sources such as wind and solar. Moreover, the Paper aims to explore the techno-economical opportunities regarding the hydrogen and e-fuel production.

A. Expansion of Wind Farms in Synergy with Power-to-X-to-Power

The proposed solution is in perfect synergy with the continuous development of new wind farms, since wind farms can assist in energizing the EB-TES-SGS system and help phase out the coal-fired boilers. The EB block transforms electricity into heat and the TES block consists of two MS tanks – one hot and one cold. The SGS block includes the MS boiler and heat exchangers responsible for transforming the stored heat into electricity. A simplified process layout of the new EB-TES-SGS plant can be seen in Figure (2), showing the similarity of the EB-TES-SGS system that was illustrated in CPP retrofitting (Figure 4).
The electricity price in Denmark depends on the neighbouring countries, as these have same prices as nearby markets approx. 90% of the time [4], allowing an efficient integration of renewables across borders [1]. During periods of cheap electricity, the EB can charge the TES system with electricity from the grid, typically in case of excess wind and/or PV. When the demand increases, and the price goes up, the TES is discharged and used to generate steam to drive the STG and feed electricity back into the grid. The integration to the DH network grants more flexibility, as the system can be optimized for both heat and power production.

B. Power-to-X-to-Hydrogen CAPEX & OPEX Vs. PRODUCTION

In the past decades, the major concern was the generation of electricity, while the current era is more concerned with the use, store, and utilization of excess generated electricity. This is where the P-X-P earned more focus, especially in countries that have reached an acceptable level of maturity towards adoption of renewable technologies. Simplest definition of P-X-P is the use of electrification (P) in the process of chemical-reaction (X) that can still in return be able to recover part of the used energy (P), not necessary in the form of electricity. The (X) factor could be regarding production of a fuel; methanol, ammonia, hydrogen, or it could be regarding storing the excess energy in molten salt medium.
In this paper, a conceptual design of an integrated system that combines the production of hydrogen and storing energy in thermal batteries is presented. The conceptual design is based on the electrification principle via utilizing excess electricity generated from wind turbines and storing it in molten-salt storage. In such configuration, the integration of storage will give flexibility in terms of purchasing electricity during low prices, thus, optimizing the size of the electrolysis. In Figure 3a, three different hydrogen production scenarios are illustrated. The given scenarios are comparable from the import-export of electricity-hydrogen, respectively, point of view.

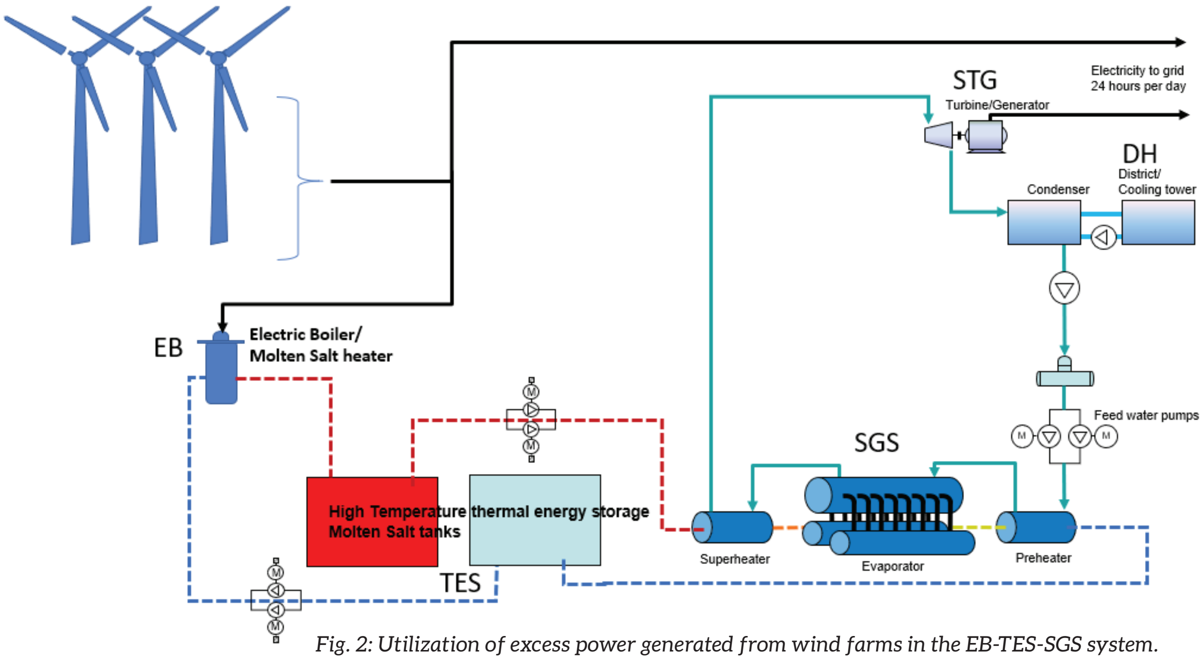

Fig. 2: Utilization of excess power generated from wind farms in the EB-TES-SGS system.

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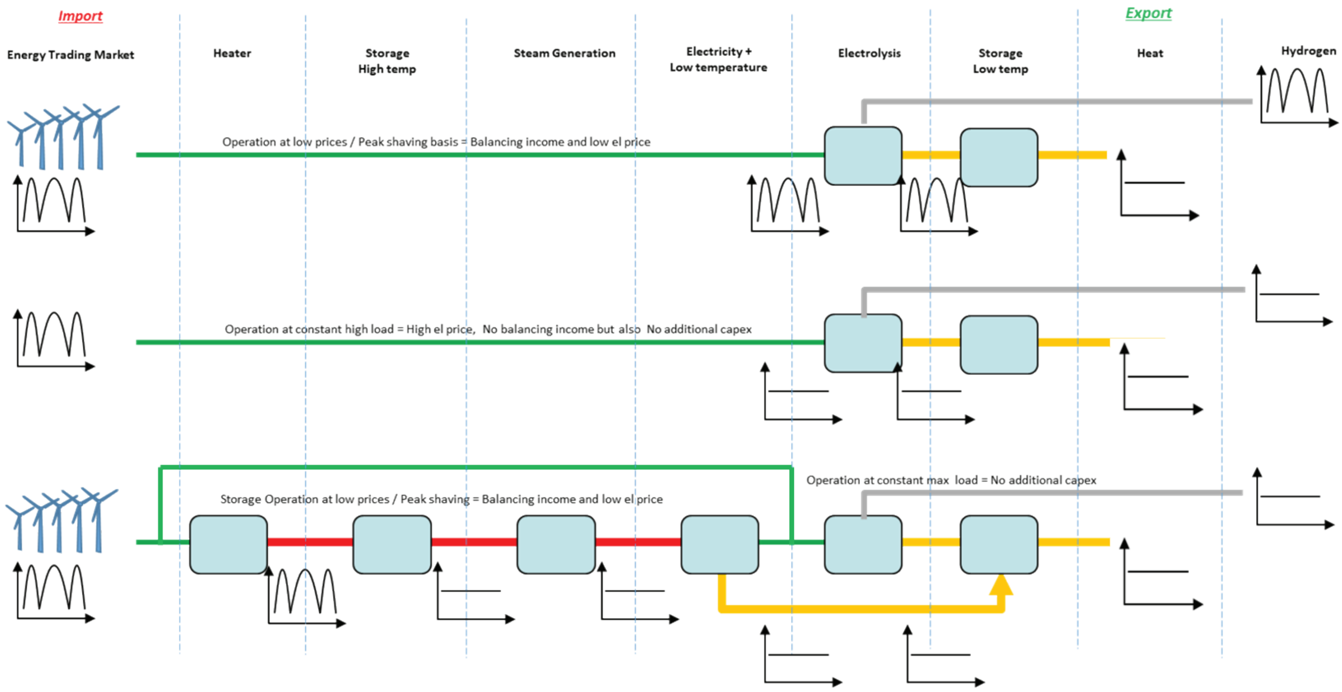


Fig. 3a. Comparative illustration of the PtX/Hydrogen configuration with respect to the import of electricity.

TABLE I

COMPARATIVE SCENARIOS OF THE P-X-HYDROGEN CONFIGURATION WITH RESPECT TO THE IMPORT OF E:ECTRICITY & INTEGRATION OF HIGH-TEMPRETURE ENERGY STORAGE.

Scenario	**Philosophy Description**	**CAPEX Vs. Availability**		**OPEX Vs. Revenue**	
Scenario A	Importing electricity during low prices, fluctuating production of Hydrogen + steady heating due to PTES	Optimized Electrolysis CAPEX + high-capacity factor		Controlled OPEX + High revenue stream	
Scenario B	Importing electricity all the time regardless of the prices, constant production of Hydrogen + steady heating due to PTES	High Electrolysis CAPEX + high-capacity factor		High OPEX + High revenue stream	
Scenario C	Importing electricity during low prices + HTTES, constant production of Hydrogen + steady heating due to PTES	Optimized Electrolysis CAPEX + high-capacity factor		Controlled OPEX + High revenue stream	
Scenario	**Philosophy Description**	**CAPEX**	**Productivity**	**OPEX**	**Revenue**
Scenario A	Importing electricity during low prices, fluctuating production of Hydrogen + steady heating due to PTES	●●	●	●●	●
Scenario B	Importing electricity all the time regardless of the prices, constant production of Hydrogen + steady heating due to PTES	●	●●	●	●●
Scenario C	Importing electricity during low prices + HTTES, constant production of Hydrogen + steady heating due to PTES	●●	●●	●●	●●

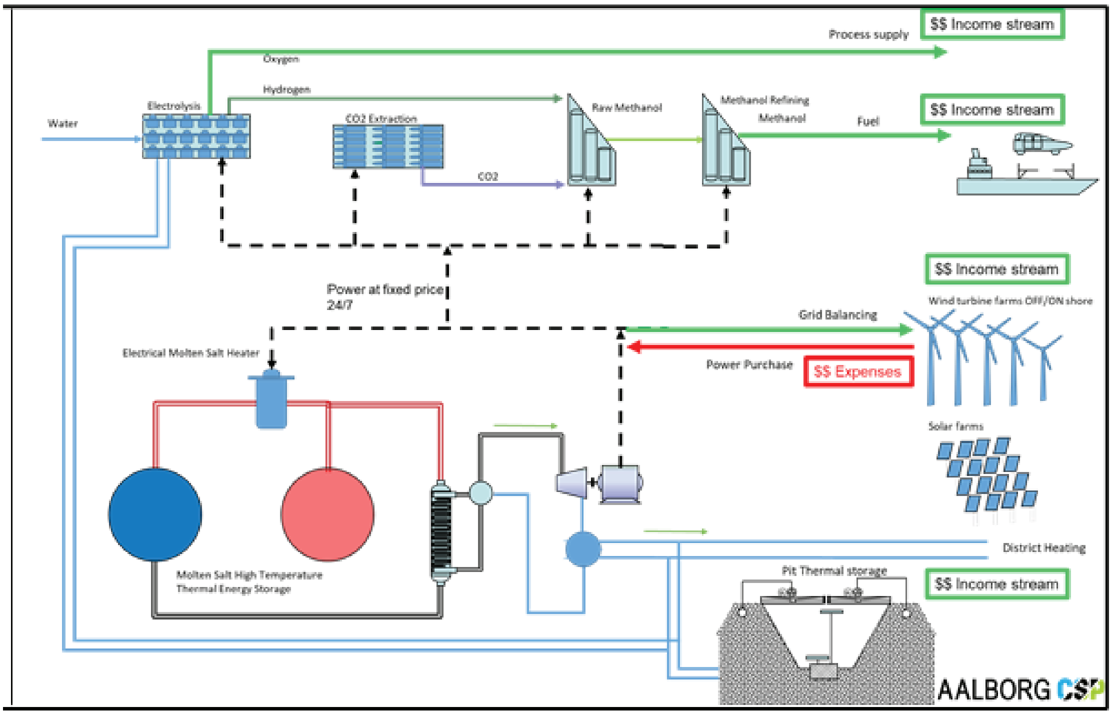
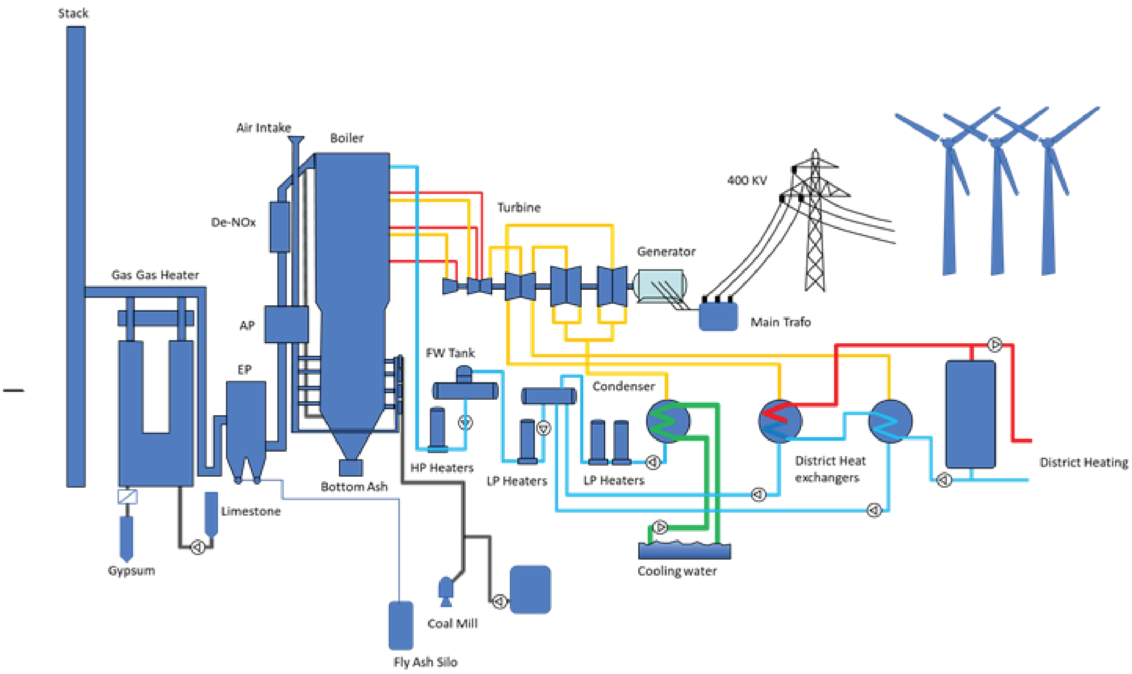


Fig. 3b. Multiple Income Streams of the PtX/Hydrogen Configuration based on Thermal Storage Intehration with Respect to Import of Electricity.

In Figure 3b, the integration of an electrified Molten Salt Thermal Energy Storage (MS-TES) to the PtX configuration is illustrated. The illustration is presented with respect to the multiple income streams from: electricity, hydrogen, and heating provided to district heating network.

C. Retrofitting of CPP with Power-to-X-to-Power

This paper presents a viable energy storage solution that can be implemented commercially in full scale and contribute to receiving both national and international CO2 reduction targets. The objective is to make a proof-of-concept by using a CPP or a renewable energy supplier (e.g. biomass plants) as a demonstration host to document the technological and commercial feasibility [1-3]. Figure 4 illustrates a typical layout of an existing CPP that generates both electricity and district heating (DH). The CPP components outlined to the right is to be replaced by the EB-TES-SGS system outlined to the left to illustrate the retrofitting concept.



 Volume 7, Issue 2, December 2021 - ISSN 2356-8569
http://dx.doi.org/10.21622/RESD.2021.07.2.052

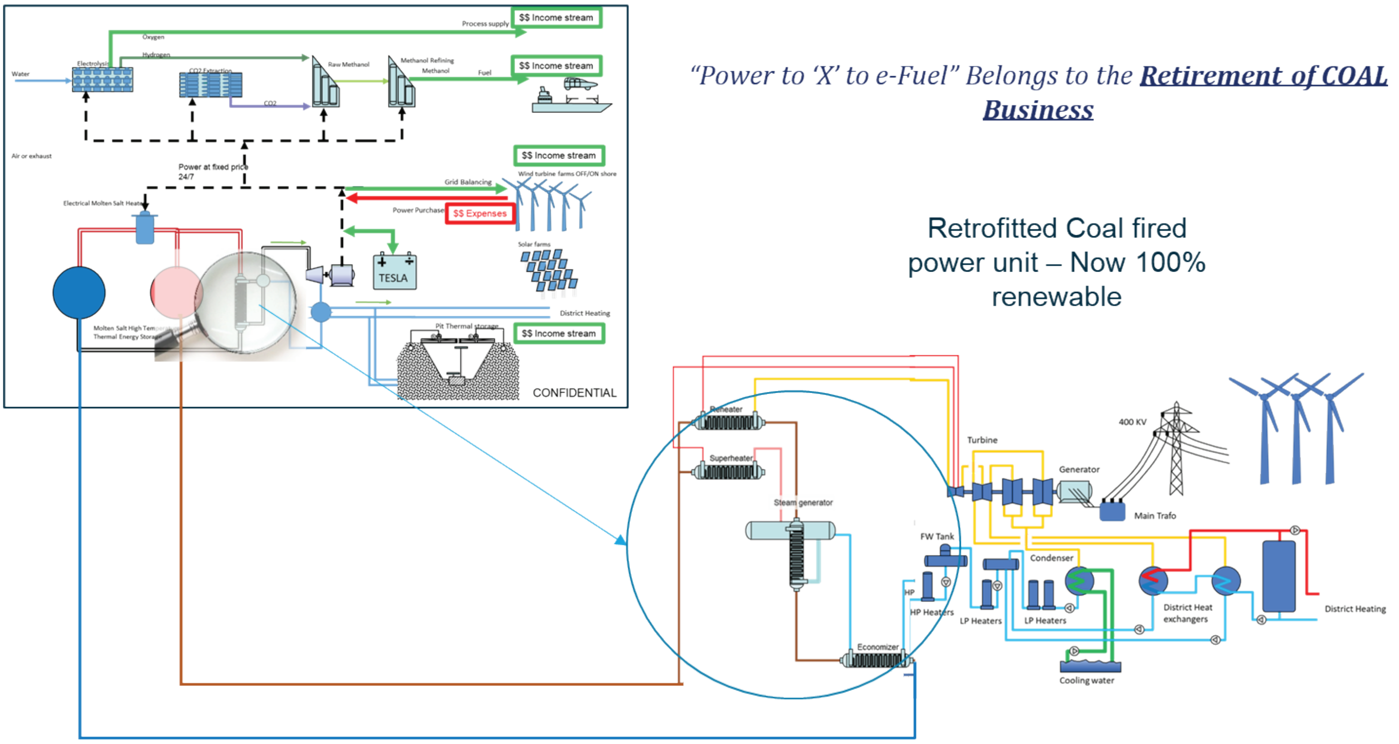


Fig. 4: A Typical CPP Including Retrofitting Proposal with Re-used Existing Assets (i.e STG)

The retrofitting concept, as shown in Figure 4, includes a replacement of main CPP components, such as the boiler and chimney. These are replaced by a package consisting of an electrical boiler (EB), a steam generation system (SGS) and a thermal energy storage (TES) system. This package is integrated with the remaining components of the CPP including the STG and high voltage equipment.

The proposed solution contributes to the grid stability in the following way. Excess power production from e.g. wind and PV is utilized to drive an EB and stored as thermal energy in a high-temperature TES.

By doing so, it is possible to improve grid stability during periods of excess electricity production. During times of power-outage in the grid, the discharge of the TES is activated together with a novel SGS, which converts hot molten salt (MS) into high-pressure superheated steam. The steam drives a turbine and generates electricity to the grid through a Rankine Cycle. The exhaust steam is condensed into hot water and injected directly into the district heating network.

Conclusion and Remarks

This section briefly summarized the findings and remarks from this paper in the following point:

- Power-to-X-to-Power concept strongly belongs to the coal sector, whether in regards to retirement of the CPP, or in regards to reducing the dependency on the coal, hence, reducing CO2 emmissions.
- Intgrating as much of possible applications is the key of maximizing the benefit from adopting the Power-to-X-to-Power concept.
- In EU market, district heating demand is high, hence, it is very encouraged to include district heating as an important focus within the Power-to-X-to-Power sector.
- In the MENA region market, district cooling is potentially a very important sector to be considered within the Power-to-X-to-Power sector.
- Investing in integration of high-temperature thermal storage within the configuration of P-X-Hydrogen gives possibility to better the tecno-economical case. However, a business case is worth investigation to conclude the comparison between Scenario B and Scenario C.

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Journal of
Renewable Energy and Sustainable Development

RESD

Volume 7, Issue 2, December 2021 - ISSN 2356-8569

ISSN 2356-8518

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