Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 7, No.1, January 2025, pp. 0250107-01 ~ 0250107-10
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v7i1.1116

Review of Reliability of Solar Hybrid Generator System as Temporary Power Supply for Offshore Industry for Sustainable Platform Application of Environmentally Friendly Energy Sources

Haryani Alamsyah[1*], Ardiansyah[2], Sunardi[3]

[1]Master Program of Electrical Engineering, Universitas Ahmad Dahlan, Yogyakarta 55191, Indonesia

[2]Informatics Department, Universitas Ahmad Dahlan, Yogyakarta 55191, Indonesia

[1,3]Electrical Engineering Department, Universitas Ahmad Dahlan, Yogyakarta 55191, Indonesia

haryani.alamsyah@gmail.com

Abstract. This paper discusses the application of two combined power generation systems namely generator and Solar Panel in improving the efficiency of offshore power supply during downtime. Ensuring reliable and sustainable power in remote and limited range environments is critical for sustainable platform maintenance and sustainability. Traditional power sources, such as diesel generators, although reliable, have high carbon emissions and operational costs. Solar energy, although environmentally friendly, faces spatial constraints in offshore. A hybrid system combines photovoltaic (PV) panels and conventional generators, which provides an optimal balance between renewable energy and reliability. This study focuses on the system design, operational benefits, and its impact on wellhead platform sustainability, highlighting its efficiency and environmental sustainability.

Keywords: Reliability, Hybrid, Offshore, Environmental, Sustainable.

(Received 2024-10-06, Accepted 2024-11-26, Available Online by 2025-01-09)

1. Introduction

During idle time of wellhead platforms [1]–[3] in offshore areas after operation must be maintained and monitored continuously. For maintenance activities, temporary power must be available continuously and reliably. Selecting a power generation system that can reduce environmental impacts without sacrificing reliability, safety and production time is important. There are many factors to consider when designing temporary supply requirements for maintenance of offshore platforms [4]. Perhaps the most

obvious are considering the distance between land and sea weather conditions, the adverse weather conditions that can occur, and the hazardous areas. These factors make access to offshore platforms very difficult, time-consuming and expensive. This is why a reliable power source is needed. Solar energy systems [5]–[8] typically provide 100% renewable energy and zero carbon emissions. However, these systems face very serious challenges when applied to offshore platforms which have limited space compared to those on land. Alternatively, gas engine generators or diesel generators can produce more power in a much smaller space than solar power, but produce high carbon emissions and have a much shorter design and life span resulting in higher operating costs. Solar hybrid generators [9]–[11] are systems that combine solar panels with conventional generators (such as solar) and/or energy storage systems (batteries) to generate electricity. This system is designed to utilize as much solar energy as possible, while conventional generators or batteries are used as backup to ensure a continuous and stable power supply. The use of solar hybrid generators can overcome the variability of solar energy by providing an additional source of power to ensure continuous electricity availability and reduce operating costs through the use of free solar energy after initial installation, as well as reducing fossil fuel consumption. Preservation for maintenance on the wellhead platform has the main purpose of ensuring the continuity of operations, safety, and efficiency of the drilling platform and oil and gas production. In this project, we carried out equipment maintenance on the wellhead platform while waiting for electricity from shore. The main preservation was carried out in the HVAC room (panel room), electrical room, and motorcycle. Preservation is carried out to prevent corrosion and damage by protecting the wellhead components from corrosion, oxidation, and material damage due to exposure to harsh marine environments, such as salt water and high humidity. In addition, preservation also ensures that the wellhead platform remains functional and reliable, reduces the risk of mechanical failures that can cause downtime and operational disruptions, and extends the operational life of wellhead components by minimizing wear and tear through effective preservation measures. Preservation can also have a significant impact on efficiency and reduce long-term maintenance costs by preventing major failures and the need for emergency repairs, thereby reducing the frequency and cost of expensive repairs, and maintaining the wellhead condition to support optimal production operations, thereby increasing the efficiency and output of oil and gas production with good preservation by ensuring that all structural components of the wellhead remain in good condition. Wellhead platform preservation involves a variety of activities, such as the application of anti-corrosion coatings, the use of inhibitors, routine inspections, and preventive maintenance. By implementing a comprehensive preservation program, companies can ensure that their wellhead platforms remain functional, safe, and efficient throughout their life cycle.

2. Methods

Preservation is an action to maintain and protect equipment from all kinds of things that cause damage to the equipment because it is stored or in a stationary condition for a long time. On large projects such as building construction, infrastructure, or industrial projects, the equipment and systems used often require special maintenance to maintain their quality and performance. Common maintenance tools used in these projects include anti-corrosion coatings, preservation of various machine components, and other measures aimed at preventing damage or reduced performance caused by environmental conditions or normal use.

Preservation equipment projects [12] also involve managing inventory of maintenance equipment, monitoring equipment condition periodically, and maintaining track records of maintenance carried out. This is important to ensure that equipment remains ready for use and does not experience damage that could cause disruption or delays in the project. Each type of public equipment has general and specific methods for maintaining it. The preservation program (sequential preservation) is ideal for application in projects.

2.1. Whellhead Platform

A wellhead platform is an offshore structure used in the oil and gas industry to house wellhead equipment, which regulates and controls oil and gas production from subsea wells. Wellhead platforms play a critical role in the extraction, preprocessing, and transportation of hydrocarbons from subsea reservoirs to further processing facilities or delivery ashore. Wellhead platforms have the benefit of providing a stable structure for oil and gas extraction operations in offshore environments. By providing production efficiency to optimize the flow and pre-processing of hydrocarbons to maximize production. In the safety aspect, namely providing critical safety systems to protect the environment and personnel from emergency events and in the maintenance aspect enabling easy access for inspection, maintenance and repair of wellhead equipment. On the wheelhead platform there are rooms and components that need to be preserved. In this project, preservation is carried out in the control room, panel room, HVAC room, motor, specheater and others.

2.2. Preservation Electrical Loads on Offshore Platform

This system has performance for the minimum electrical load required to maintain critical or important conditions of equipment or systems on the platform when it is not operating or in standby condition. These loads are designed to ensure that equipment or systems remain in operational condition and avoid damage or degradation that can occur due to long periods of inactivity. For example, in an offshore platform, some equipment or systems need to remain in optimal condition even when not in active use, such as pumps, compressors, control systems, sensors, etc. This minimum electrical load is maintained using backup power from an electric generator or other power source, and is usually adjusted to the specific needs of the equipment or system being maintained. Maintaining this electrical load is important to ensure the offshore platform can be reactivated quickly and efficiently when necessary, as well as to avoid damage or reduced performance of equipment or systems that could cause disruption in platform operations. So a hybrid system is very necessary to supply electricity during preservation. The electrical loads during preservation that will be supplied by this hybrid system are temporary AC, motor space heater, local panel space heater, and several field monitoring equipment (cameras, beacons, and Navaid). An overview of the hybrid system is presented in Figure. 1.

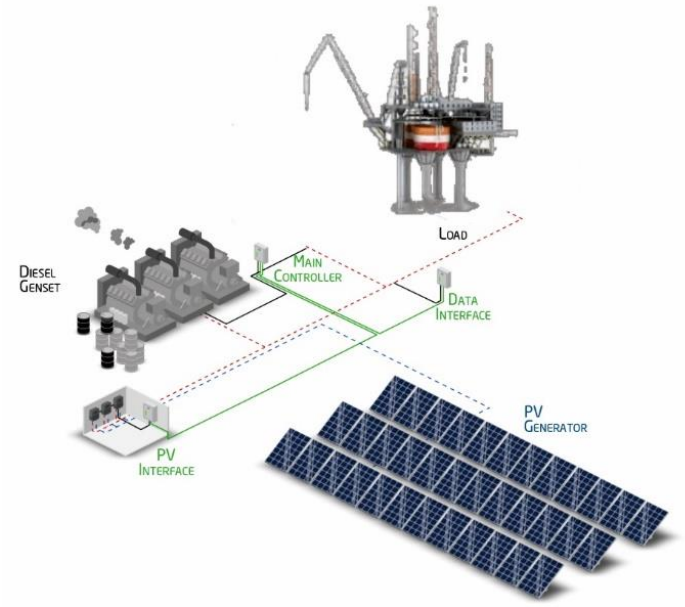

Figure 1. Solar Hybrid Generator System

2.3. Provisions of Figures and Tables

The Solar Hybrid Generator consists of several main components that work together to produce electrical energy. Some of the main components contained in the Solar Hybrid Generator as in Fig. 2 include: Solar Panels; Solar panels or solar modules are the main component that converts solar energy into electrical energy (DC electricity). Solar panels consist of solar cells made of semiconductor material that can produce electric current when exposed to sunlight. Inverters; a device that converts DC electric current produced by solar panels into AC electric current that can be used for household electrical appliances and other equipment. TEG; This component will convert the temperature difference into electrical energy. This generator is used as an additional power source when sunlight is insufficient or unavailable. Battery; used to store energy produced by solar panels or thermoelectric generators for use at night or when solar energy is not available. Batteries can also be used to store excess energy for future use. Charge Controller; used to regulate battery charging from solar panels and thermoelectric generators. This device helps protect the battery from overcharge and overdischarge. Monitoring and Control System; used to monitor system performance and regulate the operation of main components to ensure optimal energy efficiency and availability. DC-DC inverter; used to convert the DC voltage from solar panels or batteries into a DC voltage suitable for a particular use. An overview of the system is presented in the diagram and wiring of the solar hybrid generator system in Fig. 2. These components work together to produce electrical energy from renewable energy sources (solar and thermal energy) and provide a stable and sustainable electricity supply. The use of a solar hybrid generator in this system aims to reduce dependence on fuel supply for daily operations.

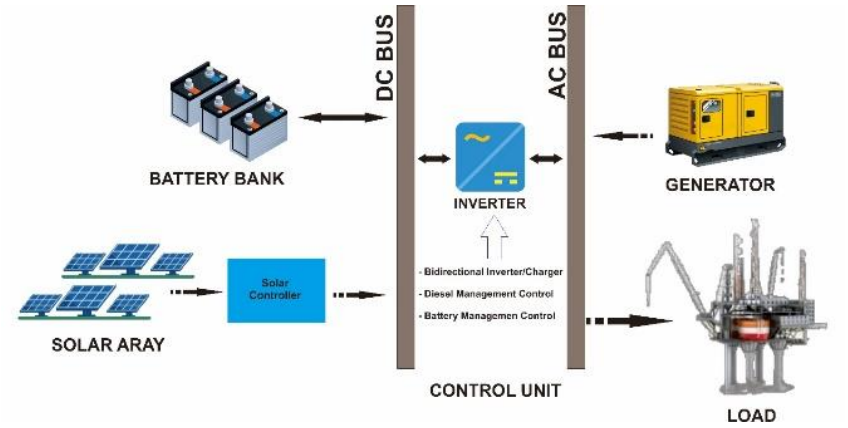

Figure 2. Diagram system solar hybrid generator

3. Results and Discussion

Preservation of this system is carried out to maintain tools that have an important function in the wellhead platform. Equipment preservation is carried out to ensure operational reliability and safety in harsh environments and often extreme weather. In this system, preservation is carried out in the HVAC room, motor room, space heater, and electrical room. This component has an important function on the wellhead platform. These components require an electricity supply that is always maintained 24 hours a day. Therefore, a power system is needed that can guarantee a continuous supply of electricity. The use of a hybrid system is expected to be able to provide a better and more efficient electricity supply.

3.1. Preservation motor and space heater

Preservation of the motor and space heater is carried out to ensure the availability of electricity for these components because these components have a very critical function. The space heater requires power that is always maintained so that its function and performance continue to work well. The function of the space heater at the wellhead is to prevent freezing and maintain optimal performance of the wellhead

equipment in cold weather conditions. Because at the wellhead, the components must be in good condition under all conditions, preservation is very necessary.

3.2. Solar Hybrid Generator

Use of a hybrid system to provide power supply to the load continuously so that the load is always in good working condition. The use of a hybrid system to anticipate failures in the load on the electricity supply. So preservation is very important to ensure the availability of electricity supply at the wellhead platform. The use of this hybrid system is able to provide electricity supply to loads that include the HVAC room, motor, space heater, and electrical room. The explanation for the solar hybrid generator is presented in the block diagram in Figure 3. In this hybrid system, it is designed to provide continuous power for loads that are always on standby for 24 hours.

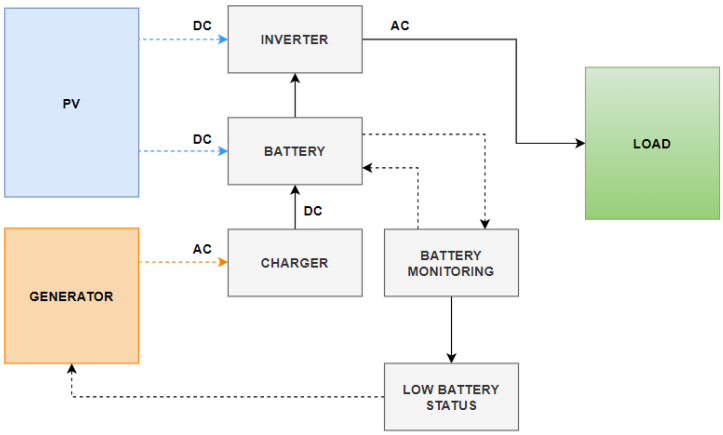

Figure 3. diagram block of solar hybrid generator

The use of a slide hybrid generator system is able to provide more optimal power to supply the load on the wellhead platform. The solar hybrid generator wiring is presented in Figure 4.

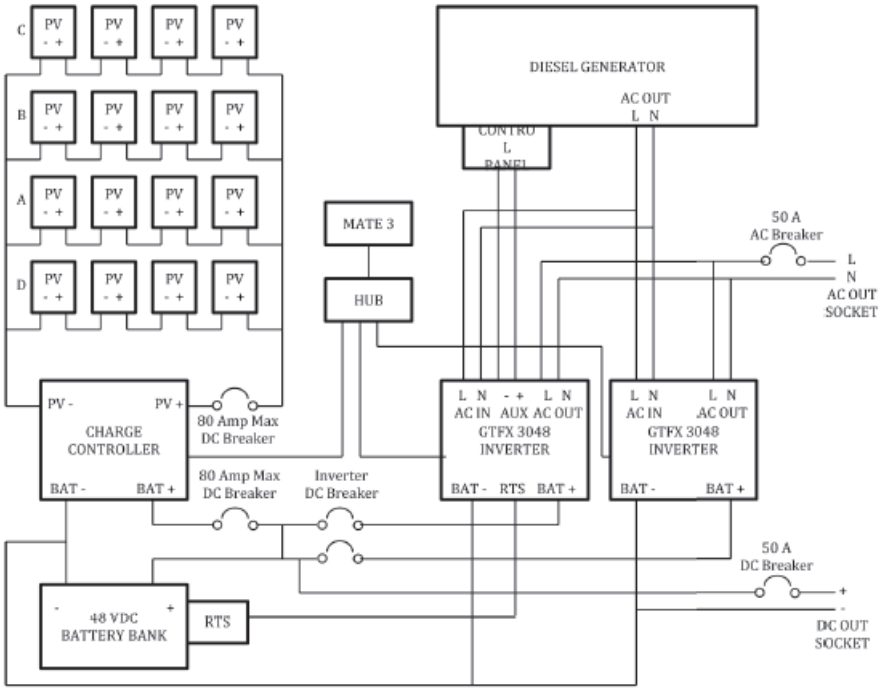

Figure 4. wiring system solar hybrid generator

3.3. Discussion

The implementation of preservation is an action that is really needed in a system, preservation on offshore platforms has a very important role in maintaining the reliability and sustainability of the platform's operations. Preservation of project equipment and materials is a process and effort to maintain and protect physical equipment against damage or destructive elements and restoration/reservation of damaged equipment parts, which are caused by factors from within (intrinsic) the archive itself or factors from outside (extrinsic) the physical equipment. itself. Because basically a project takes place in various stages and takes a long time to complete (starting from vendor fabrication, delivery, installation on the project to all equipment being tested and put into operation). The importance of preserving equipment and materials in every project is for the long-term interests of the project so that all project equipment is in good condition and there are no problems when it is operated later. Because with a good preservation program, each piece of equipment will be able to avoid quality degradation and damage during the project period (vendor fabrication, delivery, installation, commissioning and operations. The purpose of preserving the equipment and materials itself is to maintain its sustainability and extend its useful life. So that all equipment can be operated easily without problems and can last according to the initial design.

The use of a solar hybrid generator has a significant influence on the electricity supply used to supply the well head platform, temporary power including (lighting systems, motors, space heater, AC, pumps, electrical room etc.). It is important to plan and provide sufficient resources for this temporary power requirement so that operations are offshore platforms can run smoothly and safely. The use and application of this solar hybrid generator has been proven to be able to increase fuel efficiency, assist the rehabilitation process and provide system reliability.

4. Conclusion

A review of solar hybrid generators in electricity supply systems offers a number of significant advantages, both in terms of energy supply reliability, cost efficiency and environmental impact. The advantage of using this hybrid system is that it reduces dependence on fossil fuels, whose prices can fluctuate and are often unreliable.

Implementing a system located on a wellhead platform, the Solar hybrid generator can be designed modularly, allowing for additional capacity as needed without requiring major changes to existing infrastructure. By implementing a solar hybrid generator system, the supply of the load is more optimal and prevents failure of components that require continuous electricity supply. The application of solar hybrid generators to electricity supply systems offers an effective and sustainable solution to current and future energy challenges. By utilizing a combination of renewable and conventional energy sources, this technology not only improves reliability and cost efficiency but also supports important environmental sustainability initiatives.

Acknowledgments: Thanks to Universitas PGRI Semarang which facilitated the publication of the work through the publication of scientific journals along with the organizers, fellow lecturers and students who have provided motivation in participating in the activity, also thanks to all parties who cannot be mentioned one by one. Hopefully this writing work can be useful for everyone.

References

[1] E. Hilmi, E. Yandri, U. Uhanto, R. Saiful and N. Hamja, "Hybrid Energy Solutions for Sustainable Offshore Oil and Gas Opersions Leveraging Thermoelectric, Solar, and Wind Potensial", Leuser Journal of Environmental Studies volumes, Vol.2,No.2 pp.52-61,2024.

[2] O. Hassan, S. Algburi, A. Z. Sameen, H. M. Salman, M. Jaszczur "A review of hybrid renewable energy system Solar and wind-powered solusion: Challenges, opportunities, and policy implications", ELSEVIER Journal, 2024.

[3] T. G. Walmsley, M. Philipp, M. Picon-Nunez. Sameen, H. Meschede "Hybrid renewable energy utility system for industrial site A riview", ELSEVIER Journal, 2024.

[4] M. W. Jandali and K. M. Hajri, "New Innovative Approach to the Upgrade of Ageing Existing Offshore WellHead Platforms, " in International Petroleum Technology Conference, 2023, p. D011S009R002.

[5] G. G. Thory, M. R. Vora, and D. M. Stockard, "Submerged wellhead platform system, " in Offshore Technology Conference, 1990, p. OTC-6352.

[6] R. Rongsopa, "Hybrid power generation for offshore wellhead platform: a starting point for offshore green energy," in International Petroleum Technology Conference, 2011, p. IPTC-14563.

[7] V. S. Pai, "Preservation of large motors and generations from weather on offshore platforms, "IEEE transactions on industry applications, vol. 26, no. 5, pp. 914-918, 1990.

[8] A. H. Elisheikh, S. W. Sharshir, M. Abd Elaziz, A. E. Kabeel, W. Guilan, and Z. Haiou, "Modeling of solar energy systems using artificial neural network: A comprehensive riview, "Solar Energy, vol.180, pp. 622-639, 2019.

[9] E. F. Camacho and M. Berenguel, "Control of solar energy systems, "IFAC proceedings volumes, vol. 45, no. 15, pp. 848-855, 2012.

[10] S.A. Kalogirou, Solar energy engineering: processes and systems. Elsevier, 2023.

[11] M. K. H. Rabaia et al., "Environmental impacts of solar energy systems: A review, "Science of The Total Environment, vol. 754, p. 141989, 2021.

[12] S. Singh, O. I. Ibeagwu, and R. Lamba, "Thermodynamic evaluation of irreversibility and optimum performance of a concentrated PV-TEG cogenered hybrid system, " Solar Energy, vol. 170, pp. 896-905, 2018.

[13] A. F. Mirza, M. Mansoor, K. Zerbakht, M. Y. Javed, M. H. Zafar, and N. M. Khan, "High-efficiency hybrid PV-TEG system with intelligent control to harvest maximum energy under various non-static operating conditions, "Journal of Cleaner Production, vol. 320, p. 128643, 2021.

[14] C. Babu and P. Ponnambalan, "The theoretical performance evaluation of hybrid PV-TEG system, "Energy conversion and management, vol. 173,pp. 450-460, 2018.

[15] D. Despot and H. Gerhold, "Preserving tress in construction projects: Identifying incentives and barriers, "Arboriculture & Urban Forestry, vol. 29, no. 5, p. 267, 2003.

[16] V. B. Nikam and B. B. Meshram, “Modeling rainfall prediction using data mining method: A Bayesian approach, “ in 2013 Fifth International Conference on Computational Intelligence, Modelling and Simulation, 2013, pp. 132-136.
[17] Adamson K-M, Walmsley TG, Carson JK, Chen Q, Schlosser F, Kong L, et al. High-temperature and transcritical heat pump cycles and advancements: a review. Renew Sustain Energy Rev 2022;167:112798. https://doi.org/10.1016/j.rser.2022.112798.
[18] Leonzio G. An innovative trigeneration system using biogas as renewable energy. Chin J Chem Eng 2018;26:1179–91. https://doi.org/10.1016/j.cjche.2017.11.006.
[19] Forman C, Muritala IK, Pardemann R, Meyer B. Estimating the global waste heatpotential. Renew Sustain Energy Rev 2016;57:1568–79. https://doi.org/10.1016/j.rser.2015.12.192.
[20] Gazda W, Stanek W. Energy and environmental assessment of integrated biogastrigeneration and photovoltaic plant as more sustainable industrial system. ApplEnergy 2016;169:138–49. https://doi.org/10.1016/j.apenergy.2016.02.037.
[21] Klemeˇs JJ, editor. Handbook of Process Integration (PI): minimisation of energyand water use, waste and emissions. Cambridge, UK: Woodhead Publishing/Elsevier; 2013.
[22] Bhuiyan AA, Blicblau AS, Islam AKMS, Naser J. A review on thermo-chemical characteristics of coal/biomass co-firing in industrial furnace. J Energy Inst 2018;91:1 18. https://doi.org/10.1016/j.joei.2016.10.006.
[23] Klemeˇs JJ, Varbanov PS, Walmsley TG, Jia X. New directions in the implementation of pinch methodology (PM). Renew Sustain Energy Rev 2018;98: 439–68. https://doi.org/10.1016/j.rser.2018.09.030.
[24] Bhuiyan AA, Blicblau AS, Naser J. Co-firing of biomass and slagging in industrial furnace: a review on modelling approach. J Energy Inst 2017;90:838–54. https:// doi.org/10.1016/j.joei.2016.08.010.
[25] Liew PY, Theo WL, Wan Alwi SR, Lim JS, Abdul Manan Z, Klemeˇs JJ, et al. TotalSite Heat Integration planning and design for industrial, urban and renewable systems. Renew Sustain Energy Rev 2017;68:964–85. https://doi.org/10.1016/j.rser.2016.05.086.
[26] Moreira JR, Romeiro V, Fuss S, Kraxner F, Pacca SA. BECCS potential in Brazil:achieving negative emissions in ethanol and electricity production based on sugar cane bagasse and other residues. Appl Energy 2016;179:55–63. https://doi.org/10.1016/j.apenergy.2016.06.044.
[27] Klemeˇs JJ, Kravanja Z. Forty years of heat integration: pinch analysis (PA) and mathematical programming (MP). Current Opinion in Chemical Engineering 2013;2:461–74. https://doi.org/10.1016/j.coche.2013.10.003.
[28] Griffin PW, Hammond GP, Norman JB. Industrial energy use and carbon emissions reduction in the chemicals sector: a UK perspective. Appl Energy 2018;227:587–602. https://doi.org/10.1016/j.apenergy.2017.08.010.
[29] Linnhoff B, Hindmarsh E. The pinch design method for heat exchanger networks. Chem Eng Sci 1983;38:745–63.
[30] Sandberg E, Toffolo A, Krook-Riekkola A. A bottom-up study of biomass andelectricity use in a fossil free Swedish industry. Energy 2019;167:1019–30. https://doi.org/10.1016/j.energy.2018.11.065.
[31] Dhole VR, Linnhoff B. Total site targets for fuel, co-generation, emissions, and cooling. Comput Chem Eng 1993;17:S101–9. https://doi.org/10.1016/0098-1354(93)80214-8.
[32] García JL, Porras-Prieto CJ, Benavente RM, G´omez-Villarino MT, Mazarr´on FR. Profitability of a solar water heating system with evacuated tube collector in the meat industry. Renew Energy 2019;131:966–76. https://doi.org/10.1016/j. renene.2018.07.113.
[33] Perry S, Klemeˇs JJ, Bulatov I. Integrating waste and renewable energy to reduce the carbon footprint of locally integrated energy sectors. Energy 2008;33:1489–97. https://doi.org/10.1016/j.energy.2008.03.008.

[34] Eiholzer T, Olsen D, Hoffmann S, Sturm B, Wellig B. Integration of a solar thermalsystem in a medium-sized brewery using pinch analysis: methodology and case study. Appl Therm Eng 2017;113:1558–68. https://doi.org/10.1016/j. applthermaleng.2016.09.124.
[35] Ghaffour N, Bundschuh J, Mahmoudi H, Goosen MFA. Renewable energy-driven desalination technologies: a comprehensive review on challenges and potential applications of integrated systems. Desalination 2015;356:94–114. https://doi.org/10.1016/j.desal.2014.10.024.
[36] Sabiha MA, Saidur R, Mekhilef S, Mahian O. Progress and latest developments of evacuated tube solar collectors. Renew Sustain Energy Rev 2015;51:1038–54. https://doi.org/10.1016/j.rser.2015.07.016.
[37] Chowdhury JI, Hu Y, Haltas I, Balta-Ozkan N, Gjr Matthew, Varga L. Reducing industrial energy demand in the UK: a review of energy efficiency technologies and energy saving potential in selected sectors. Renew Sustain Energy Rev 2018;94:1153–78. https://doi.org/10.1016/j.rser.2018.06.040.
[38] Sokhansefat T, Kasaeian A, Rahmani K, Heidari AH, Aghakhani F, Mahian O. Thermoeconomic and environmental analysis of solar flat plate and evacuatedtube collectors in cold climatic conditions. Renew Energy 2018;115:501–8. https://doi.org/10.1016/j.renene.2017.08.057.
[39] Lauer M, Dotzauer M, Millinger M, Oehmichen K, Jordan M, Kalcher J, et al. The Crucial Role of Bioenergy in a Climate-Neutral Energy System in Germany. Chem Eng Technol n.d.;n/a. https://doi.org/10.1002/ceat.202100263..
[40] Nkwetta DN, Smyth M, Zacharopoulos A, Hyde T. Experimental field evaluation of novel concentrator augmented solar collectors for medium temperature applications. Appl Therm Eng 2013;51:1282–9. https://doi.org/10.1016/j.applthermaleng.2012.08.006.
[41] Taibi E, Gielen D, Bazilian M. The potential for renewable energy in industrial applications. Renew Sustain Energy Rev 2012;16:735–44. https://doi.org/10.1016/j.rser.2011.08.039.
[42] Thr¨an D, Seidenberger T, Zeddies J, Offermann R. Global biomass potentials resources, drivers and scenario results. Energy for Sustainable Development 2010;14:200 5.https://doi.org/10.1016/j.esd.2010.07.004.
[43] Milani D, Abbas A. Multiscale modeling and performance analysis of evacuatedtube collectors for solar water heaters using diffuse flat reflector. Renew Energy 2016;86:360–74. https://doi.org/10.1016/j.renene.2015.08.013.
[44] Cheng W, Zhang Y, Wang P. Effect of spatial distribution and number of rawmaterial collection locations on the transportation costs of biomass thermal power plants. Sustain Cities Soc 2020;55:102040. https://doi.org/10.1016/j.scs.2020.102040.
[45] Colangelo G, Favale E, Miglietta P, de Risi A. Innovation in flat solar thermal collectors: a review of the last ten years experimental results. Renew SustainEnergy Rev 2016;57:1141–59. https://doi.org/10.1016/j.rser.2015.12.142.
[46] Ehrmann N, Reineke-Koch R. Selectively coated high efficiency glazing for solar- thermal flat-plate collectors. Thin Solid Films 2012;520:4214–8. https://doi.org/10.1016/j.tsf.2011.04.094.
[47] Hamelin L, Borzęcka M, Kozak M, Pudełko R. A spatial approach to bioeconomy: quantifying the residual biomass potential in the EU-27. Renew Sustain Energy Rev 2019;100:127–42. https://doi.org/10.1016/j.rser.2018.10.017.
[48] Cindrella L. The real utility ranges of the solar selective coatings. Sol Energy Mater Sol Cell 2007;91:1898. https://doi.org/10.1016/j.solmat.2007.07.006.–901.
[49] Muscat A, de Olde EM, de Boer IJM, Ripoll-Bosch R. The battle for biomass: a systematic review of food-feed-fuel competition. Global Food Secur 2020;25: 100330. https://doi.org/10.1016/j.gfs.2019.100330.
[50] Youcef-Ali S. Study and optimization of the thermal performances of the offset rectangular plate fin absorber plates, with various glazing. Renew Energy 2005; 30:271–80. https://doi.org/10.1016/j.renene.2004.04.009.

[51] Rehfeldt M, Worrell E, Eichhammer W, Fleiter T. A review of the emission reduction potential of fuel switch towards biomass and electricity in European basic materials industry until 2030. Renew Sustain Energy Rev 2020;120:109672. https://doi.org/10.1016/j.rser.2019.109672.
[52] Moss R, Shire S, Henshall P, Arya F, Eames P, Hyde T. Performance of evacuated flat plate solar thermal collectors. Therm Sci Eng Prog 2018;8:296–306. https://doi.org/10.1016/j.tsep.2018.09.003.