Plan Overview

A Data Management Plan created using DMPonline

Title: Linear Fresnel Reflector–Wind Hybrid Power Plants: Techno-Economic Analysis, Multi-Objective Optimisation, and Environmental Assessment

Creator: Ahmed Aljudaya

Principal Investigator: Ahmed Aljudaya, Derek Ingham, Mohammed Pourkashanian, Lin Ma

Data Manager: Ahmed Aljudaya

Project Administrator: Derek Ingham, Mohammed Pourkashanian, Lin Ma

Contributor: Ahmed Aljudaya, Derek Ingham

Affiliation: The University of Sheffield

Template: Postgraduate Research DMP (The University of Sheffield)

ORCID iD: 0000-0002-2872-9536

Project abstract:

Current energy production depends heavily on fossil fuels and conventional power plants, which harm the environment and raise concerns about global warming. Moving towards renewable energy technologies is essential to reduce the impact of global warming, the increasing of global energy demand, and greenhouse gas emissions. To accomplish this, reducing reliance on fossil fuels is necessary. Most of the European and North American countries have already shifted towards renewables decades ago, as well as developing countries that have recently joined them to achieve the zero-greenhouse gas emissions goal. Remarkably, choosing which renewable energy technology to install in any country depends on the available resources and other significant reasons. It mainly relies on geographical, environmental, technical, and economic reasons. For the Middle East and northern Africa, in desert regions, solar energy would be a suitable technology to be installed since its location is in the Sunbelt. Particularly, concentrated solar power is applicable in the Gulf Countries (GCC) due to the high Direct Normal Irradiation (DNI). The concentrated solar radiation is used to increase the temperature of the heat transfer fluid, and then the steam generated is used to drive the turbine in order to generate electricity. The Linear Fresnel Reflector (LFR) technology is a promising short-term solution for shifting to clean energy production due to its capability to utilise the existing Rankine cycle in conventional power plants. An attempt to unravel the optical, thermodynamic, and economic weaknesses of a large-scale LFR technology is performed in this report. The research gaps have been identified, examined, and validated to achieve cost-effective optical performance. Mainly, the report includes an introduction, literature review, materials and methods, and preliminary results. The report proposes a techno-economic assessment of a 50-MW linear Fresnel reflector concentrated solar power. A molten salt thermal energy storage system is examined using the System Advisor Model (SAM) software, which has been selected as the validation, simulation, and optimisation tool for the assessment.

ID: 69105

Start date: 30-09-2019

End date: 30-06-2026

Last modified: 30-06-2026

Linear Fresnel Reflector–Wind Hybrid Power Plants: Techno-Economic Analysis, Multi-Objective Optimisation, and Environmental Assessment

Defining your data

- What data will you collect or create during the project?
- How will the data be collected or created, and over what time period?
- What formats will your digital data be in?
- Approximately how much digital data will be generated during the project?
- Are you using pre-existing datasets? Give details if possible, including conditions of use

Since the main focus of this research is targeting Concentrated Solar Power (CSP) technology and its hybridisation with wind energy, the data that will be collected include weather files, Linear Fresnel Reflector (LFR) commercial power plant specifications, wind turbine and wind resource data, techno-economic parameters, and life-cycle inventory data regarding the studied technologies. The data collection took place primarily in the first two years of the study, while additional wind, hybridisation, and environmental datasets were gathered as the scope expanded into the later stages. The data creation (simulation, optimisation, and life-cycle assessment) started in the last three months of the first year and continued throughout the assessment.

Firstly, the weather files will be in CSV, TXT, TMY2, TMY3, and (.EPW) formats since the optimisation tool (the System Advisor Model) is able to import all the above-mentioned formats. Other weather parameter inputs can be imported as a plain text file or entered manually. The main sources of this data are the National Renewable Energy Laboratory (NREL) and the METEONORM software, which compiles long-period ground and satellite records. For the studied location of Duba, Saudi Arabia, a METEONORM dataset was selected to provide a consistent, long-term solar and wind resource basis for the region, since reliable long-term ground-measured files were difficult to obtain for many sites across the country. All gathered datasets are imported and stored in the SAM library. In addition to the solar resource, the same files provide the wind resource inputs (wind speed and direction at the measurement height) used in the wind feasibility and wind-farm assessment.

Secondly, the technical and commercial parameters of the existing power plants will be collected from multiple resources and used in Word format. This includes the design specifications and published annual performance metrics of the molten-salt ISG-LFR reference plant used for validation, together with parameters drawn from a peer-reviewed techno-economic study used as a secondary cross-check. Wind turbine data, including power curves, hub-height options, and specific-power characteristics for the screened utility-scale candidates, were also collected in this category from manufacturer datasheets and published sources.

Thirdly, the collected techno-economic data will be in .txt files, and the created data will be calculated, optimised, and generated with the help of the LK scripting language. Because full automation of SAM through LK was challenging, a semi-automated workflow was developed to manage the large number of simulations underpinning the staged parametric analysis of the DSG, ISG, ISG-TES, and ISG-TES-FFF configurations. This data can be described in different simulation formats, and the generated results can be illustrated in CSV or Word files. The financial assumptions used in the analysis, particularly the land lease and cost estimates for the Saudi Arabian case, were assembled from global pricing benchmarks, international reports, and representative cases from the United States and Europe and were tested through sensitivity analysis across a range of values.

Fourthly, a substantial body of data is generated by the hybrid optimisation stage. A structured parametric database of several thousand SAM configurations was created by co-varying the solar multiple, thermal energy storage duration, wind capacity, and fossil fuel fraction. This database, stored in CSV format, was used to fit interpolation-based surrogate models in MATLAB, which were then validated against the original SAM simulations before being used within a genetic algorithm, multi-objective optimisation. The optimisation outputs, including the Pareto-optimal solution sets and the TOPSIS multi-criteria rankings, are generated and stored in CSV and MATLAB data formats, with summary results presented in Word and figure files.

Fifthly, the environmental assessment generates a separate life-cycle inventory dataset. Component-level inventory data for the solar field, receivers, power block, thermal energy storage, balance of plant, and wind subsystem were collected from multiple peer-reviewed sources and assembled into a cradle-to-grave inventory, since no single published study provides this inventory for a molten-salt ISG-LFR configuration. These data are entered into the SimaPro software using the Ecoinvent database and assessed with the ReCiPe 2016 Midpoint method. The inventory inputs, characterisation factors, and resulting impact data are stored in Word and CSV formats.

A large amount of data is expected to be generated throughout this study since the simulation and optimisation cover hundreds of parameters across multiple software tools. The total size of the digital data has grown from around 25 GB in the early stage to several hundred gigabytes, reflecting the addition of the wind, hybridisation, surrogate modelling, and life cycle datasets. Three main publications are expected to be the output of this assessment, covering the standalone LFR techno-economic analysis, the hybrid multi-objective optimisation, and the life-cycle assessment, with each one generating around ten main datasets. Where an optimisation is applied to different configurations or scenarios, this multiplies the generated data accordingly. Thus, the overall approximate number of generated datasets, including the intermediate parametric and surrogate runs, reaches into the hundreds of thousands.

Finally, pre-existing datasets are used in the validation process to examine the capability of the selected simulation tools. The molten-salt ISG-LFR model was validated against the published performance of an operational reference plant and cross-checked against an independent techno-economic study, while the surrogate models were validated against the original SAM database. Some other technical parameters of commercial power plants are collected from manufacturers or peer-reviewed data in previous publications. The life-cycle inventory similarly draws on established sources and the Ecoinvent database under its standard conditions of use. To maintain consistency, the collected data from different resources will be analysed technically. For example, two-step validation and simulation are proposed to achieve more accurate results. That is a short summary of all collected and generated digital data that will be used throughout this extensive study.

Looking after your data

- How will you make data easier to understand and use? *(e.g. creating a README file)*
- Where will you store digital and physical data during the project?
- How will you name and organise your data files?
- How will you ensure data is backed up? *(e.g. using [University research data storage](#))*
- How often will you check your backup files? *(e.g. on backup, at set intervals)*
- Will you use extra security precautions for any of your digital or physical data? *(e.g. for sensitive and/or personal data)*

At this stage of the research, the number of collected and simulated data is still manageable, so clear files' names will be sufficient. the number of data used can be stored digitally in multiple folders in the laptop as well as in Google drive. README files are prepared and will be shared when in near future; however, organizing the files in folders and subfolders is enough for the first year of the study. Some of collected data will not be edited throughout the research process such as weather files, so it will be stored in the SAM library as well as the above-mentioned digital drives. These files will be named according to the region name and/or the altitude and longitude of the targeted region.

In near future, using the University research data storage is essential to ensure the data is backed up safely. all backed-up files will be checked weekly by the main candidate, especially the developed datasets. the collected, simulated, and optimized files will be stored in the select simulation tool (SAM).

Archiving your data

- What data will be archived (stored on a long-term basis) at the end of the project?
- How long will the data be stored for? *(e.g. standard TUoS retention period of 10 years)*
- Where will the archive be stored? *(e.g. subject-specific repository, or [ORDA](#))*
- Who will archive the data? *(e.g. you, or your supervisor)*
- If you plan to use storage other than a repository, who will be responsible for the data?

At the end of the project, the optimization codes and input technical and economical parameters will be archived for a minimum of 10 years in ORDA (the University of Sheffield research data repository). I will be responsible for storing the important data on a long-term basis. Since ORDA does not specify a particular subject, the selected repository may change during the project to increase the discoverability of the developed data. Some of achieved data are already stored in ORDA data base.

Sharing your data

- How will you make your data available outside the research group after the project? *(e.g. through data repository, or access on request via data availability statement)*
- Will you make all of your data available, or are there reasons you can’t do this? *(e.g. personal data, commercial or legal restrictions, very large datasets)*
- How might you make more of your data available? *(e.g. anonymisation, participant consent, analysed data only)*
- What licence might you attach to your data to say how it can be reused and shared?

After and during the project, if a specific repository (other than ORDA) is selected for achieving the data, the dame repository will be used for sharing data outside the research group. On the other hand, since this project will form multiple publications, access on request via data availability statement might be used. The data sharing will be clear in the end of the third year of this project since the first paper will be published during this time. Most of the data will be available at the end of this project if there is no legal restrictions. if very large datasets prevents publishing all available data, the plan will to divide the datasets to make increase data availability as much as possible. Analyzed data only or participant consent may help to make more data available for long-term curation. To allow reusing and to protect the available data by the end of this project, the Open Data Commons Attribution License (ODC-By) might be attached to the data.

Implementing your plan

- Who is responsible for making sure the plan is followed? *(e.g. you, your supervisor)*
- How often will the plan be reviewed and updated? *(e.g. if the project changes, yearly)*
- What actions have you identified from the rest of this plan? *(e.g. selecting a repository, requesting University research data storage)*

The candidate and the supervisors will be responsible for making sure the plan is followed and the work is progressing. Data collection, metadata production, and file-backup updates will be the responsibility of the main candidate. The plan will be presented, reviewed, updated every six month throughout the project. The DMP has been a valuable tool of comparing different available repositories and identifying the capability of the University research data storage. Both services improves the data safety and availability.

Planned Research Outputs

Conference proceeding - "A comparative study of the techno-economic performance of the concentrated solar power using direct and indirect steam generation: a case study of the linear Fresnel reflector under high direct normal irradiance"

Researchers, power companies, and state politicians have given concentrated solar power (CSP) much attention for its capacity to generate large amounts of electricity while overcoming the intermittent nature of solar resources. Among all CSP technological types, the linear Fresnel reflector is well known for cost reduction, low land use factor, and low optical efficiency. The LFR was considered a cost-effective alternative option to the parabolic trough collector (PTC) because of its simplistic design, and this often outweighs its lower efficiency. The LFR is a promising option for directly producing steam to a thermal cycle in order to generate low-cost electricity, but it has also been shown to be promising for indirect steam generation.

In the DSG power plant, the heat exchanger can be eliminated because pressurised water can reach very high temperatures without the need for a heat exchanger. Additionally, the antifreeze protection system is not required since the water does not freeze at high temperatures, and this is unlike other heat transfer fluids (HTS). Recently, multiple HTFs showed a feasible thermodynamic performance since they can reach a temperature of up to 550 °C of the solar field (SF) output temperature.

The purpose of this analysis is to compare the annual performance of the DSG and ISG LFR power plants using molten salt and other different HTFs to investigate their technical and economic effects. A 50 MWe solar-only system is examined as a case study for both steam production methods in extreme weather conditions. A parametric analysis is carried out to determine the optimal solar field size that provides the lowest levelised cost of electricity while achieving the highest technical performance.

As a result of optimizing the solar field size, the solar multiple (SM) is found to be between 1.2 and 1.5 in order to achieve as low as 9 cents/KWh for the direct steam generation of the linear Fresnel reflector. In addition, the power plant is capable of producing around 135 GWh annually and up to 35% of the capacity factor, while the ISG produces more energy but at a higher cost. The direct and indirect steam generation of the LFR shows sufficient performance. However, further analysis is required since the ISG exhibits higher thermal performance, but the DSG offers a cheaper electricity price.

Publication - "Techno-Economic Assessment of Molten Salt-Based Concentrated Solar Power: Case Study of Linear Fresnel Reflector with a Fossil Fuel Backup under Saudi Arabia’s Climate Conditions"

Concentrated solar power (CSP) has gained traction for generating electricity at high capacity and meeting base-load energy demands in the energy mix market in a cost-effective manner. The linear Fresnel reflector (LFR) is valued for its cost-effectiveness, reduced capital and operational expenses, and limited land impact compared to alternatives such as the parabolic trough collector (PTC). To this end, the aim of this study is to optimize the operational parameters, such as the solar multiple (SM), thermal energy storage (TES), and fossil fuel (FF) backup system, in LFR power plants using molten salt as a heat transfer fluid (HTF). A 50 MW LFR power plant in Duba, Saudi Arabia, serves as a case study, with a Direct Normal Irradiance (DNI) above 2500 kWh/m2. About 600 SM-TES configurations are analyzed with the aim of minimizing the levelized cost of electricity (LCOE). The analysis shows that a solar-only plant can achieve a low LCOE of 11.92 ¢/kWh with a capacity factor (CF) up to 36%, generating around 131 GWh/y. By utilizing a TES system, the SM of 3.5 and a 15 h duration TES provides the optimum integration by increasing the annual energy generation (AEG) to 337 GWh, lowering the LCOE to 9.24 ¢/kWh, and boosting the CF to 86%. The techno-economic optimization reveals the superiority of the LFR with substantial TES over solar-only systems, exhibiting a 300% increase in annual energy output and a 20% reduction in LCOE. Additionally, employing the FF backup system at 64% of the turbine’s rated capacity boosts AEG by 17%, accompanied by a 5% LCOE reduction. However, this enhancement comes with a trade-off, involving burning a substantial amount of natural gas (503,429 MMBtu), leading to greenhouse gas emissions totaling 14,185 tonnes CO_2 eq. This comprehensive analysis is a first-of-a-kind study and provides insights into the optimal designs of LFR power plants and addresses thermal, economic, and environmental considerations of utilizing molten salt with a large TES system as well as employing natural gas backup. The outcomes of the research address a wide audience including academics, operators, and policy makers.

Planned research output details

Title	DOI	Type	Release date	Access level	Repository(ies)	File size	License	Metadata standard(s)	May contain sensitive data?	May contain PII?
A comparative study of the techno-economic perform ...		Conference proceeding	2023-05-05	Open	None specified		Creative Commons Attribution 4.0 International	None specified	No	No
Techno-Economic Assessment of Molten Salt-Based Co ...	10.3390/en17112719 ...	Publication	2024-06-03	Open	None specified		Creative Commons Attribution 4.0 International	None specified	No	No