*Journal Homepage: -* www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

**Article DOI:** 10.21474/IJAR01/20030
**DOI URL:** http://dx.doi.org/10.21474/IJAR01/20030

*RESEARCH ARTICLE*

# MODERNIZING AND OPTIMISING EFFICIENCY OF THE GRID INFRASTRUCTURE FOR DECARBONIZATION

**Aadarsh Jayadeep**

……………………………………………………………………………………………………....

## Manuscript Info

*Manuscript History*
Received: 07 October 2024
Final Accepted: 09 November 2024
Published: December 2024

## Abstract

This paper concludes that any system that may be employed for decarbonization in the big market may be applied to other electricity markets around the world. For e.g., The Eastern region in India, boasting substantial wind and solar power resources, presents a significant opportunity for decarbonizing the electricity sector. Transitioning to a generation system primarily reliant on renewable energy sources is technically feasible but necessitates substantial capital investments in new wind, solar, and potentially nuclear units, as well as energy storage and regeneration infrastructure. However, the implementation of such investments in a freemarket economy is projected to increase electricity generation costs for corporations by a factor ranging from 2.9 to 3.7. Given that these costs are typically passed on to consumers through price hikes, decarbonization efforts may disproportionately affect the less affluent segments of the population, exacerbating poverty and inequality within the region. In alignment with U.N. sustainability goals and to mitigate the adverse impact of decarbonization on vulnerable communities, it is imperative to introduce energy subsidies targeted at lower-income citizens as part of public policy measures. These subsidies can help alleviate the financial burden of increased electricity costs, thereby promoting equity and inclusivity within the state while advancing towards a cleaner and more sustainable energy future.

……………………………………………………………………………………………………....

## Introduction:-

Since 2021, the global energy shortage issue has escalated, with the International Energy Agency (IEA) reporting in its "2022 electricity market report" a slight decline in global electricity demand in 2020 followed by growth in 2021. However, the world's reliance on coal-fired power generation has kept its power industry's cleanliness relatively low despite reaching a 34.5% proportion of non-fossil energy in 2021, leading to high carbon emissions.

In line with international carbon neutrality goals, 127 countries have committed to reducing their carbon footprint. Looking ahead, Dubai's power system aims to integrate energy conservation, efficiency improvements, and carbon emission reduction targets. The clean development of power industry is crucial for achieving carbon neutrality, as the sector plays a vital role in carbon emission control. However, it faces challenges due to the uneven distribution of power resources, resulting in higher transportation costs and energy losses.

**Corresponding Author:- Aadarsh Jayadeep**

Similarly, India's power system also grapples with issues related to the integration of renewable energy, with concerns about grid stability and energy balance. Additionally, the COVID-19 pandemic and associated measures have disrupted economic activity, impacting power supply, grid operation, and market transactions. Dubai's transition to a low-carbon power industry necessitates the development of a new power system capable of addressing these challenges. This system will serve as a crucial driver for promoting the city's low-carbon transformation and sustainable energy future.

### Problem Definition

Power decarbonization necessitates a significant increase in the proportion of new energy sources, posing challenges for traditional power systems, such as those within Dubai Electricity and Water Authority (DEWA). These systems are complex networks with multiple stakeholders, including producers and consumers, operating as interconnected input-output systems. Constructing a power system requires integrating various components like energy supply, the power grid, and the supply chain to ensure efficient and coordinated evolution.

While systematic analyses have yielded insights into key factors for low-carbon power industry development, there's still a need for further exploration. This project seeks to innovate by elucidating the crucial factors influencing the low-carbon development of the power system within DEWA's grid. It aims to validate the support provided by technology, market mechanisms, and policy frameworks for low-carbon development through modeling. By theoretically and empirically analyzing different regional development contexts, to unveil the pathways toward achieving low-carbon objectives within the power industry. This project will contribute to enhancing understanding and guiding practical strategies for transitioning towards a sustainable and low-carbon power system within the DEWA grid of Dubai.

### Outline Of The Project

**Compilation of Comprehensive Open Dataset**:

1. Gather time series data on renewable potentials and load profiles, alongside information on green energy inflows.
2. Collect geospatial data on local grid demand to map out demand patterns effectively.
3. Acquire tabular data covering power plant capacities, grid topology, and various energy demand scenarios to understand the infrastructure's dynamics.

**Development of ETSAP-TIAM Modelling Framework:**

1. Customize the ETSAP-TIAM modelling framework to create a bottom-up, process-oriented model.
2. Integrate detailed energy supply, conversion, and end-use technologies within the model.
3. Enhance the model to include a single-sector economy sub-model and a reduced-form climate model, enabling interaction among energy, economy, and climate systems.

**Implementation of Energy System Optimization Modelling:**

1. Utilize Power BI and Py-PSA to prioritize decarbonization pathways within the energy system.
2. Focus on integrating high-share renewable energy sources and enhancing energy efficiency.

## Literature Review:-

### High Carbon Emission of Power Generation:

An Excerpt from "Influencing Factors and Realization Path of Power Decarbonization"— Based on Panel Data Analysis of 30 Provinces in China from 2011 to 2019 (Int J Environ Res Public Health. 2022 Dec; 19(23): 15930) - By Xiufan Zhang and Decheng Fan

1. In this paper, it is found that power generation decarbonization is the key to improving the energy efficiency of coal-fired power generation. However, under the growing demand for power generation, the proportion of traditional energy used in conventional power sources is relatively high. The clean capacity of thermal power is rather low. Coal-fired generating units are installed with environmental protection facilities; however, the mediation process of energy-saving power generation dispatching will generate stop losses, bring variable costs, generate higher operation and maintenance costs, and increase the cost of power generation enterprises.
2. The data from 42 thermal power plants in China in 2020 and found that input redundancy, high carbon emission intensity of power supply, and heating are the main reasons for low carbon emission efficiency. The resource allocation and input-output structure of the power supply should be adjusted to achieve carbon emission reduction in the power industry. The change in power generation structure is an important method to reduce carbon emission intensity.

3. The Data envelopment analysis (DEA) method to measure wind power efficiency in 30 provinces in China from 2012 to 2017 and pointed out that improving wind power efficiency will help China achieve energy conservation and emission reduction targets. While vigorously advancing new energy, the development of conventional energy should be coordinated. The technological upgrading of thermal power should be accelerated.

### Generation Sector Decarbonisation

Decarbonization of the electricity generation sector and its effects on sustainability goals- Efstathios E. Michaelides, Sustainable Energy Research Volume 10, Article number: 10 (2023)

This paper concludes that any system that may be employed for decarbonization in the big market may be applied to other electricity markets around the world. For e.g., The Eastern region in Texas, boasting substantial wind and solar power resources, presents a significant opportunity for decarbonizing the electricity sector. Transitioning to a generation system primarily reliant on renewable energy sources is technically feasible but necessitates substantial capital investments in new wind, solar, and potentially nuclear units, as well as energy storage and regeneration infrastructure. However, the implementation of such investments in a free- market economy is projected to increase electricity generation costs for corporations by a factor ranging from 2.9 to 3.7. Given that these costs are typically passed on to consumers through price hikes, decarbonization efforts may disproportionately affect the less affluent segments of the population, exacerbating poverty and inequality within the region. In alignment with U.N. sustainability goals and to mitigate the adverse impact of decarbonization on vulnerable communities, it is imperative to introduce energy subsidies targeted at lower-income citizens as part of public policy measures. These subsidies can help alleviate the financial burden of increased electricity costs, thereby promoting equity and inclusivity within the state while advancing towards a cleaner and more sustainable energy future.

In a market-oriented economy these costs will be passed to the consumers. The complete transition of the electricity generation sector to renewables will have the following effects for the society:

1. The CO2 emissions of the electricity generation industry will plummet—a very desirable societal effect.
2. The quantity of the generated electric energy will increase because of the dissipation in the storage-regeneration process. While not desirable, this effect can be accommodated by the society at large.
3. The price of electricity in the region will increase because of the costs associated with the infrastructure—a very undesirable societal effect.

If all the currently operating fossil-fuel units are decommissioned and when the renewable subsidies are faced out (in 2032), the estimates of the future electricity price for the consumers will normalize even after inflation, given the enormity of the undertaking for the decarbonization of the system, this price range is reasonable. This estimate represents a significant increase in the current retail electricity prices in the residential sector (by a factor between 2.9 and 3.7). The estimate is also in line with the current electricity prices paid in several countries, which generate a high fraction of their electricity by renewables and use only a limited amount of energy storage.

### Net-Zero Energy Buildings (NZEB):

Decarbonization of Net Zero Energy Buildings by an Intelligent Energy Management System for Smart Grids- Seif Eldin A. Shorbila; Osama M. Hebala; Hamdy A. Ashour- 11th International Conference on Power Science and Engineering (ICPSE)-IEEE Transactions on Smart Grids, 2011

### Significance of Buildings in Energy Consumption and GHG Emissions:

Buildings consume a substantial portion of the world's electric power, predominantly sourced from fossil fuels, leading to significant greenhouse gas (GHG) emissions. The high energy demand of buildings underscores the urgency of developing sustainable solutions to mitigate their environmental impact.

### Introduction of Net Zero Energy Buildings (NZEBs) Concept:

The concept of Net Zero Energy Buildings (NZEBs) emerges as a promising solution to reduce energy consumption and GHG emissions in buildings. NZEBs integrate on- site grid-connected Distributed Energy Resources (DERs) to generate the energy required for building operations.

### Challenges Associated with NZEBs:

Despite the potential of DERs to generate surplus energy in NZEBs, a negative cost gap between imported and exported energy poses challenges. The cost disparity increases the payback time of DER installations, impacting the economic viability of NZEBs.

### Impact of Grid Connection on NZEBs:

Connecting NZEBs to electric fossil fuel utility grids introduces challenges related to energy consumption and generation patterns. Mismatches between on-site energy generation and consumption can lead to increased GHG emissions, undermining the environmental benefits of NZEBs.

### Implementation of Energy Storage Systems (ESS):

A proposed solution involves installing Energy Storage Systems (ESS) in NZEBs and controlling their charging and discharging power. The implementation of controllers, such as Proportional Integral (PI) and Fuzzy Logic Controller (FLC), aims to optimize the operation of ESS and regulate power injection into utility grids.

### Open-Dataset Modeling

### Timeseries data of load profile:

To assess the possibility of decarbonization within Dubai's DEWA grid, each utility station was modelled as a node, positioned at its geometric center. These nodes were interconnected via existing and planned transmission lines, as outlined in the National Grid Infrastructure. Despite the absence of specific data on line connections to substations or power plants, a heuristic approach was taken to establish these links, ensuring the construction of an accurate grid topology.

The analysis comprised of four main stages: **pre-processing, mapping, aggregating, and representing, with geospatial analysis** facilitated through the geopandas package in Python. By adopting this comprehensive methodology, a robust model for evaluating decarbonization strategies within Dubai's local grid was constructed

### Model Requirements:

The primary objective of the Dubai Electricity and Water Authority (DEWA) Energy Grid Simulation (MEGS-Modeling Energy and Grid Services) model is to simulate both traditional thermal generation-based electricity systems, which have been prevalent until recently, and fully decarbonized electricity systems anticipated in the future. These future systems are expected to incorporate a diverse range of generation and storage technologies. MEGS aims to provide outputs that are most relevant for system planners and policymakers, aiding them in identifying technology portfolios that lead to reduced emissions while ensuring system security and minimizing costs for consumers.

To meet the requirements of modeling the DEWA grid, the model had to fulfill several criteria:

1. **Generation Technologies**: The model must accurately define the technical characteristics of both thermal and variable renewable technologies. This includes resolving generation dynamics on an hourly basis for solar, on a weekly basis for wind to capture weather patterns, and on a seasonal basis to account for variations in renewable resource availability.
2. **Storage Technologies**: Given the importance of energy storage in decarbonizing the grid, the model must track the state of charge of storage technologies to prevent energy storage limits from being exceeded. This necessitates solving timesteps in a chronological sequence rather than using a representative time-slice approach.
3. **System Security**: It must demonstrate the ability to provide essential grid services to all regions, including maintaining a sufficient margin of firm capacity over demand, supplying upwards frequency response and fast-acting reserve, and ensuring a minimum level of inertia at each timestep to ensure grid stability.
4. **Regional Considerations**: The model must balance generation and imports with demand and exports for each model region and meet system security constraints in each region. Inter-regional transmission lines can be utilized to transfer energy or meet reserve requirements.
5. **Computation Speed:** To enable efficient scenario analysis, it should be capable of running hundreds or thousands of scenarios overnight on an average computer. This requires an efficient problem formulation and the ability to trade off resolution with runtime.

In summary, the model is designed to simulate the complex dynamics of the DEWA grid, providing valuable insights for decision-makers to navigate the transition to a more sustainable and efficient electricity system in Dubai.

**Assumption 1:** Generation technologies may only operate in one of three modes, with a fourth mode for storage.

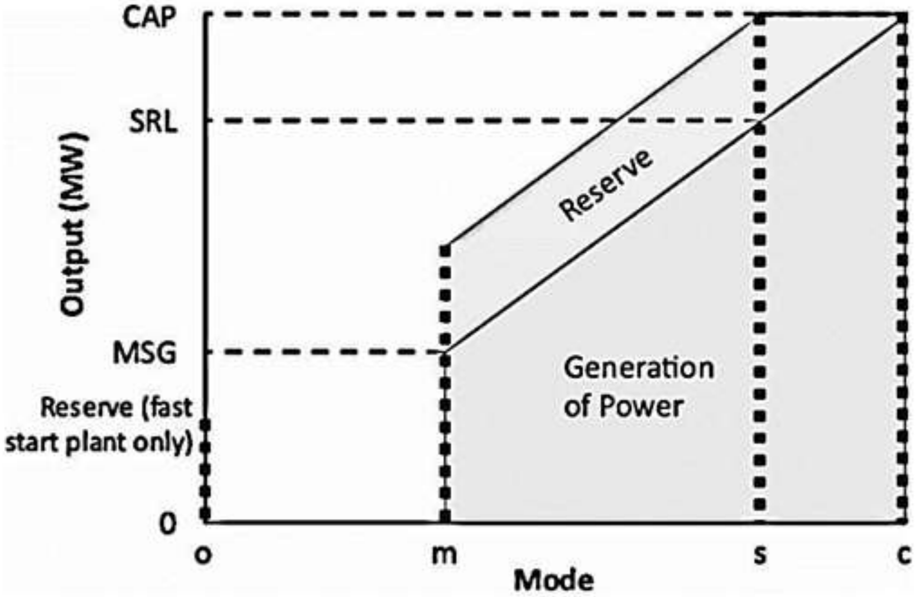


**Fig. 3.1:-** Illustrates by showing generation and reserve outputs for the allowed operating regime between MSG and full capacity of a typical thermal generator. (CITED FROM POWER PLANT DOCUMENTATION FOR SIEMENS CCGT AGS 01).

The production of energy and provision of grid services of these modes is illustrated in fig where:

1. **Capacity (CAP in MW),** is the nameplate capacity
2. **Minimum Stable Generation (MSG in MW),** is defined as the lowest possible output if the unit is on
3. **Spinning Reserve Level (SRL in MW),** is defined as the highest possible output if the unit is providing all possible upwards reserve

**Assumption 2: Within each day, storage is optimized alongside generation on a perfect foresight basis:** Optimization of intra-day timesteps occurs concurrently rather than in a sequential manner. This approach ensures that all-time series data impacted by weather conditions, such as renewable energy availability, demand, and reserve requirements, are considered by the optimizer for every timestep within the day. In the case of hydrogen power, predicted inflow within the day is utilized, and short-term storage must maintain the same storage level at the start and end of the day. Similarly, long-term storage must begin and end the day with different storage levels, adjusted by the budgeted discharge or charge amount.

**Governing equations:**

The energy transition model is based on the complete decarbonization of the grid. With systems such as the one depicted in **Fig. 3.1** distributed throughout the region, the model uses the pertinent energy balances to ensure that the hourly power demand is always satisfied. For this reason, an hour-by-hour energy balance computation was performed using the hourly demand data in the database on the supply side, and the energy sources were hierarchically arranged in the following way:

1. The thermal power plants operate continuously as base-load plants.
2. The wind and solar farms generate power during all times when their power is available. Part or all of this renewable power is instantaneously fed to the grid. Any excess power is stored.
3. Power from the “Other Sources,” (which amounts to a maximum of 1,300 MW) is flexible and fed to the grid when the demand is high enough for the power from the nuclear, wind, and solar sources to be insufficient to satisfy the demand.
4. When all the power sources have been utilized, any excess demand is supplied by the stored BESS, using fuel cells and inverters.

For the hourly demand–supply simulation, the electric energy production/generation during the hour of the year, **i**, is:

$E_{Pi}=E_{wPi}+E_{Spi}+E_{Tpi}+E_{Opi}$

Where, **E** denotes the electric energy; the subscript **P** denotes production; and the second subscripts **W, S, N, and O** denote wind, solar, thermal and others, respectively. The hourly generation of the additional wind and solar units has been calculated using the regionally averaged generation capacity, in MWh per MW installed, of the currently operational wind units and PV units in the region.

At the same hour, **i**, the energy stored or recovered from storage is equal to the difference between the energy generated **($E_{pi}$)**, and the energy demanded **($E_{di}$)** by the grid:

$\Delta E_{si}=E_{pi}-E_{di}$

Energy dissipation (energy losses) is associated with the energy storage/recovery processes. The dissipation is taken into account in the computations by the efficiencies of the electrolysis process, **$\eta_{el}$,** and of the fuel cells, **$\eta_{fc}$**. The stored energy (energy storage level) in the next hour, the (i + 1)th hour, is:

$E_{si+1}=E_{Si} + (\Delta E_{si})\eta_{el}$ **if $E_{pi} > E_{di}$**

$E_{si+i}=E_{Si} - (\Delta E_{si})\eta_{fc}$ **if $E_{pi} < E_{di}$**

Where, **$E_{si}$** is the energy storage level at the previous hour, i. The equation essentially determines the dissipation of the storage-regeneration process:

The value **$\eta_{el}$ =** 75% is used in the simulations of this study. Fuel cell efficiencies are currently in the range 60% < **$\eta_{fc}$** < 85% and the value **$\eta_{fc}$**= 75% is used in the simulation.

The two values of the efficiencies have been chosen to be lower than the optimum efficiencies because they include the efficiencies of the auxiliary equipment, such as the maximum power point trackers (MPPTs), inverters and transformers. After assessing the progress of low-carbon development within the Dubai Electricity and Water Authority (DEWA) grid, we delve into examining the trajectory of the new power system and analyze regional scenarios. By conducting heterogeneity analysis, it offers insights into the foundational aspects and future prospects of power development across various regions within the DEWA grid.

**Fig 3.2:-** Grid Utility modelled using Power BI to analyse the load profile of the generating station for a virtual timeseries data set.

**Py-PSA Earth Model:**

A natural way to address the lack of power grid data is to utilize open geospatial datasets. Currently, a few open-source packages have been published to extract and build networks from such datasets such as SciGrid. However, each package focuses on applications for a particular world region rather than on the global coverage and there still needs to be a ready- to-use solution which could be implemented into a global model. To fill this gap, an original approach which reconstructs the network topology by relying solely on open globally- available data. The developed approach is based on the OpenStreetMap (OSM) datasets that are a crowd-sourced collection of geographic information, which is daily updated and includes geolocation references.

To address the computational complexity of solving a co-optimization problem involving transmission and generation capacity expansion, the model incorporates advanced spatial clustering methods adapted from the PyPSA package and PyPSA-Global model. These clustering techniques enable the aggregation of system nodes to reduce model complexity, thus minimizing computational requirements.

The available clustering methods focus on various aspects, including:
1. Preserving the representation of renewable potentials and transmission grid topology.
2. Accurately representing electrical parameters to enhance estimates of electrical power flows.
3. Aggregating spatially proximate nodes without considering other network characteristics.

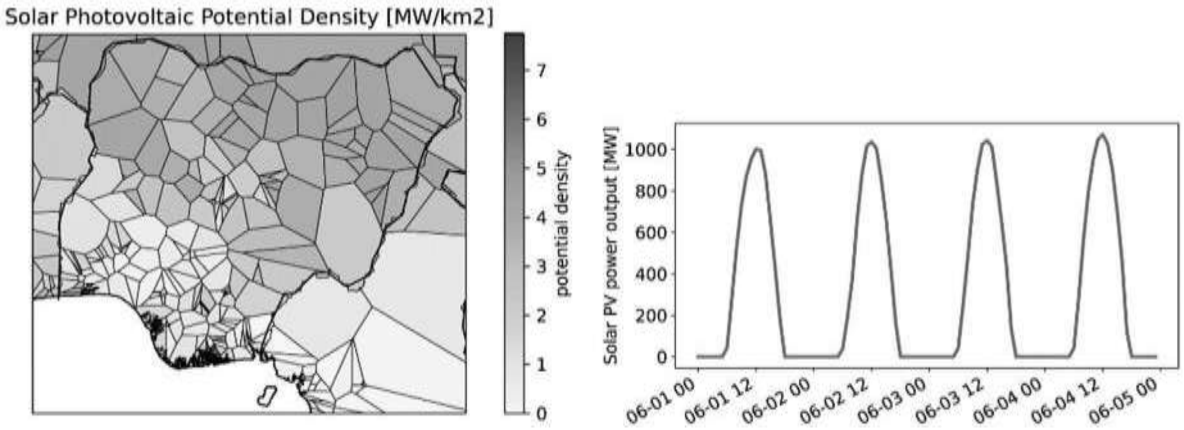


**Fig.3.3:-** Py-PSA Earth Model Indicating the OpenStreetMap (OSM) dataset to collect crowd-sourced PV Generation Density on a Unilateral model to utilise geospatial potentials of green energy.

**ETSAP-TIAM (Energy Technology Perspectives TIMES Model):**

To model the DEWA grid, the ETSAP-TIAM modelling framework was utilized. This involves:
1. **Framework Selection:** Choosing ETSAP-TIAM as the modeling framework for its comprehensive capabilities in energy system analysis and optimization.
2. **Data Integration:** Incorporating relevant data on the DEWA grid, including infrastructure details, energy generation sources, transmission lines, and demand patterns.
3. **Model Customization**: Adapting the ETSAP-TIAM framework to accurately represent the DEWA grid's characteristics, such as node configurations, transmission capacities, and connection points.
4. **Scenario Development**: Creating scenarios to simulate various decarbonization pathways, considering factors like renewable energy integration, energy efficiency improvements, and sector coupling.
5. **Simulation and Analysis**: Running simulations within the ETSAP-TIAM model to assess the performance of different decarbonization strategies on the DEWA grid. This includes evaluating metrics like carbon emissions, energy reliability, and economic viability.

## Results Interpretation:-

Analyzing the simulation results to identify promising decarbonization pathways and understand their implications for the DEWA grid's future sustainability and resilience.

Summary of the four energy and climate policy scenario groups evaluated in the model. Each scenario group is drawn from the probability distributions outlined in **Table A.** Consistency is maintained across the four scenario groups by sampling the various random input parameters of ETSAP-TIAM identically.

| Scenario family | Policy implemented |
|---|---|
| BASE_SSP2 | This outlines the evolution of the global energy system in alignment with current studies and policies, serving as a benchmark for evaluating future policy scenarios. |
| 2C_SSP2 | Introduces to the BASE_SSP2 scenario a global constraint of 2 °C as the maximum post-industrial temperature change from 2020 onwards to 2100 |
| 2C_SSP2_DA30 | In this scenario, the model follows the BASE_SSP2 trajectory until 2030, by postponing ambitious climate change mitigation policies. After 2030, it takes climate change mitigation action by considering the remaining $CO_2$ emissions budget. |
| 1p5c_OS_SSP2 | Introduces to the BASE_SSP2 scenario a global constraint of 1.5 °C as the maximum post-industrial temperature change from 2020 onwards to 2100 |

**Table A:-** Etsap Tiam Framework Policies.

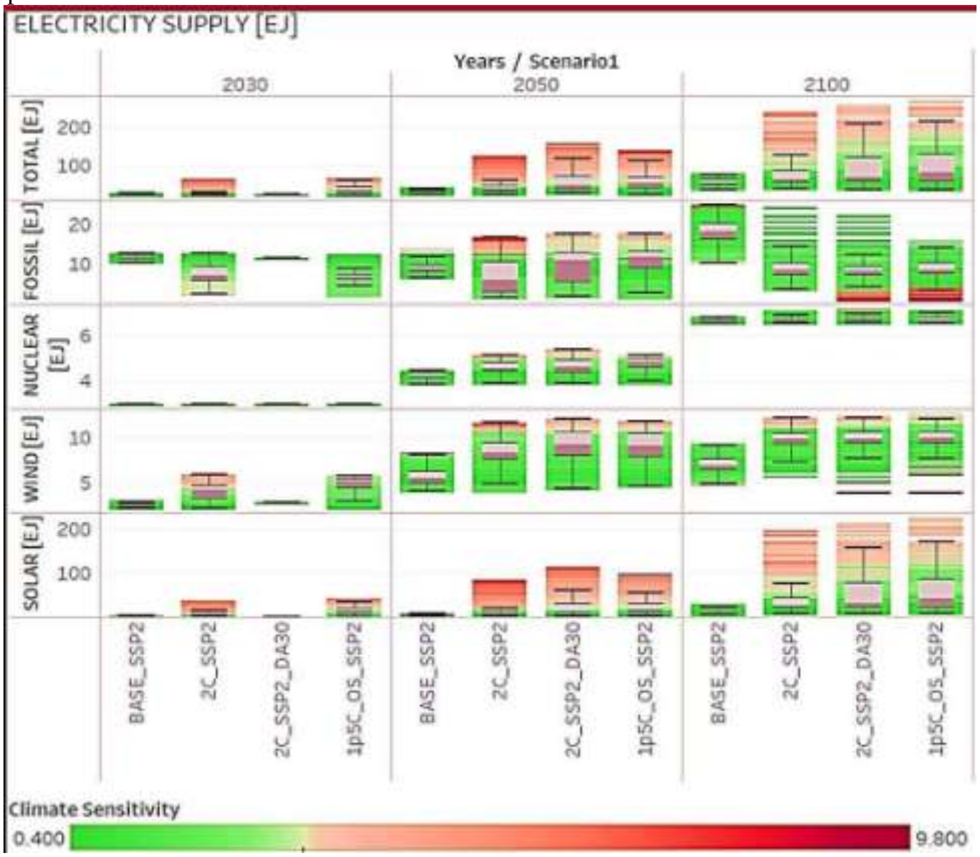


**Fig. 3.4:-** ETSAP-TIAM Framework Model: The histograms depict the global green energy supply distribution projected for 2050 under various climate change mitigation scenarios, measured in PJ/yr. On the x-axis, the bins represent ranges of PJ/yr., while the y-axis illustrates the frequency of occurrences within each bin.

**Fig. 3.5 Illustrates the flow of green energy into storage systems, electrolysers, and instances of curtailment.**

## Results and Developments:-

### Simulation Results:

1. In the context of decarbonization within the Dubai grid, the model defines energy storage in terms of its storage horizon, which represents the period during which operators can optimize arbitrage opportunities. This horizon is determined by the user as a multiple of the storage duration. For instance, a storage facility with a 12-hour storage capacity would require at least 24 hours for a full cycle, accounting for idle time and operations with intermediate or low load factors. Typically, the storage horizon is set between 5 and 10 times the duration of storage.
2. For long-term storage facilities, the model utilizes previously calculated seasonal average demand data based on a 10-year dataset for each region. Half-hourly timeseries are derived by averaging 10 years of half-hourly demands for the same day of the year. Similarly, regional capacity factors for renewables are calculated by averaging data over 10 years. It constructs a "seasonal average" net demand curve for the region, considering known renewable capacities and subtracting output from the averaged demand.
3. Furthermore, the ETSAP_TIAM generates a "perfect foresight" net demand curve for the region by subtracting renewable generation (based on availability timeseries) from the demand timeseries for the scenario year. These two timeseries are combined to create a "limited foresight" net demand curve, either for the specific region where the storage is located or for the entire system if storage generation could exceed demand. The limited foresight curve for day 1 is entirely based on the perfect foresight curve, while for days beyond the weather horizon (typically 7 days), the forecast relies entirely on the seasonal average curve. Between these extremes, the forecast is a blend of the two, with the proportion of perfect foresight decreasing over time. This process is illustrated graphically in **Fig 4.1**

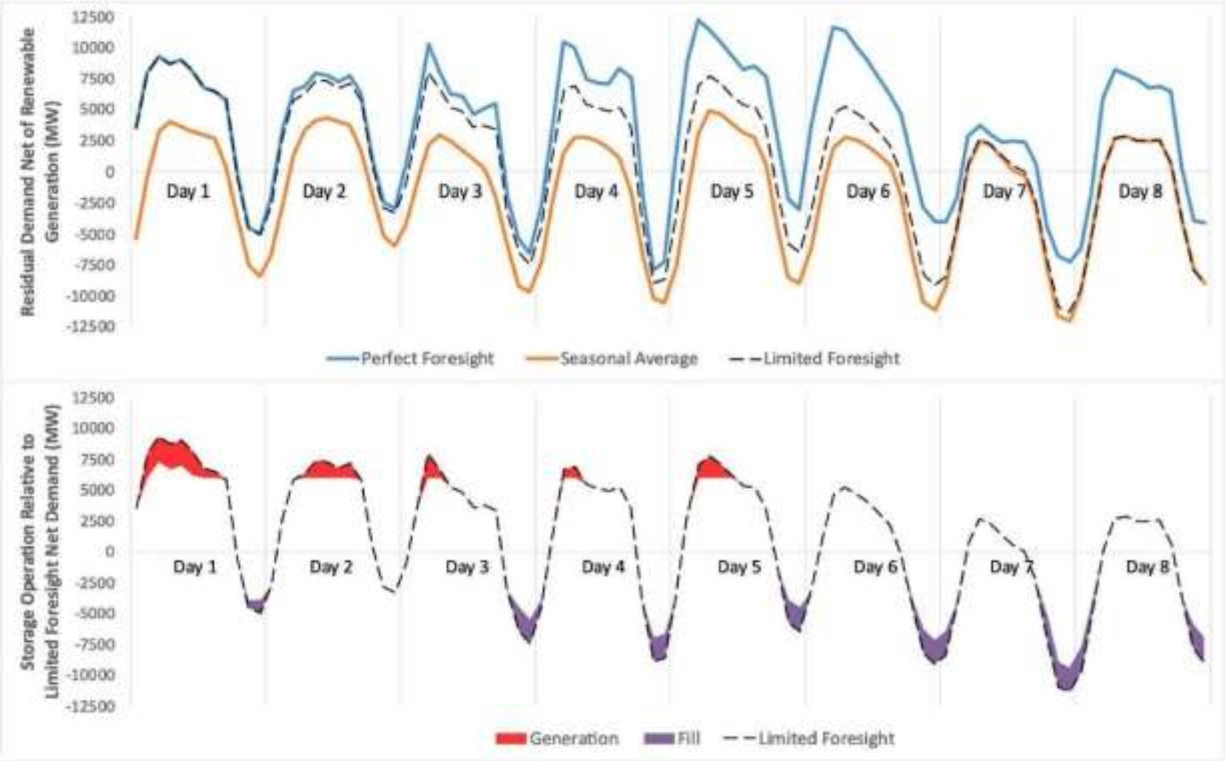


**Fig. 4.1:-** Composition of the modelled limited foresight net demand curve (top) and simulated storage operation (bottom)over an eight-day period.

### Individual Contributions:

1. Integrate the real-time power plant scenarios from the CCGT into the dashboard using the available data from the SQL server provided by the DBA team.
2. Visualise the PV array data from the Py-PSA OSM module for the nodes connected to the simulated feeder and incorporate Peak Shaving Algorithm using the HIL Testbed.
3. Evaluate the baseline and sub_s2 scenarios of the ETSAP-TIAM model using the evaluation index and weigh the tertiary and secondary indicators to obtain the climate sensitivity histogram for four such evaluations.

**Collaborative Contributions:**

1. Simulate and test the HIL to study the impact of microgrid performance with BESS
2. Assess the ETSAP-TIAM framework for the node-division of the feeder using the ETAP integrated HIL module.
3. Conduct test scenarios for the four schemes under the framework for various decentralised systems to measure the evaluation index for various timeframes of the modelled data.

**Measurement of Evaluation Index:**

Because each observation index varies in attributes and dimensions, the average method is employed to standardize dimensions. The min-max normalization method is commonly used to normalize the original data. Let O = (**oij**)_m*n represent the original data matrix, and x = (**xij**)_m*n denote the normalized matrix, where (i = 1, 2, …, m; j = 1, 2, …, n). The conversion formulas are as follows:

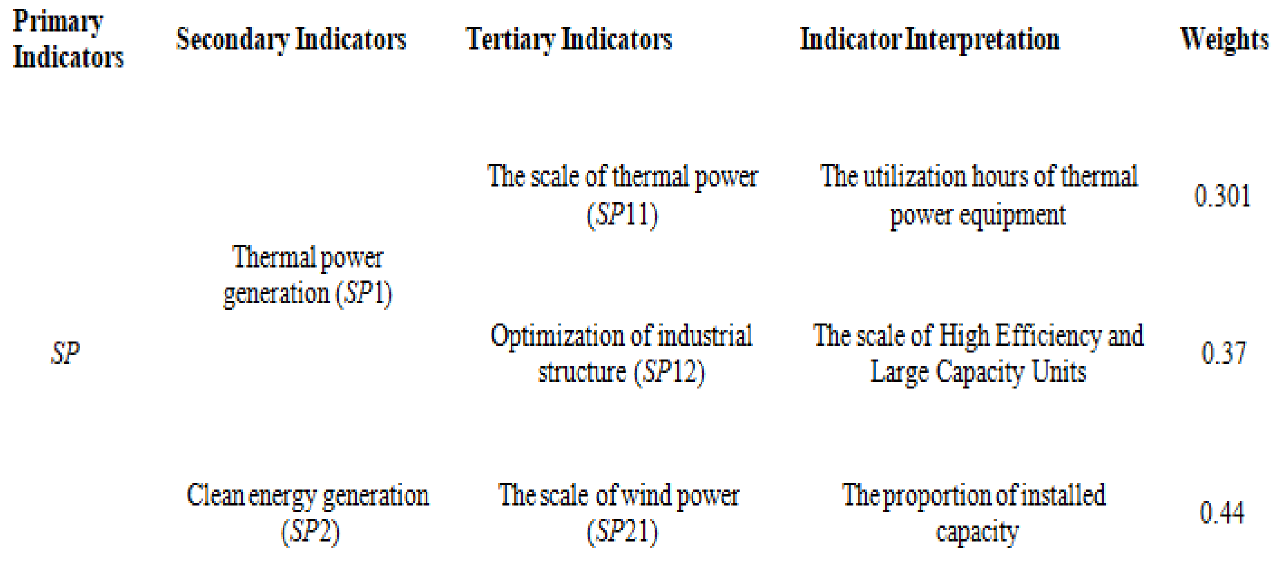
**For positive indicators:**

$$x_{ij} = \frac{o_{ij} - \min(o_j)}{\max(o_j) - \min(o_j)}, i = 1, 2, 3, \ldots, n$$

**For negative indicators:**

$$x_{ij} = \frac{\min(o_j) - o_{ij}}{\max(o_j) - \min(o_j)}, i = 1, 2, 3, \ldots, n$$

**Table B**:- Evaluation index system of the net-carbon level of the power industry based on ETSAP_TIAM framework:



| Primary Indicators | Secondary Indicators | Tertiary Indicators | Indicator Interpretation | Weights |
|---|---|---|---|---|
| *SP* | Thermal power generation (*SP*1) | The scale of thermal power (*SP*11) | The utilization hours of thermal power equipment | 0.301 |
| | | Optimization of industrial structure (*SP*12) | The scale of High Efficiency and Large Capacity Units | 0.37 |
| | Clean energy generation (*SP*2) | The scale of wind power (*SP*21) | The proportion of installed capacity | 0.44 |

| Primary Indicators | Secondary Indicators | Tertiary Indicators | Indicator Interpretation | Weigh |
|---|---|---|---|---|
| | The scale of integration (SP22) | | Connection rate | 0.42 |
| | Photovoltaic power generation (SP3) | Solar photovoltaic industry scale (SP31) | The proportion of photovoltaic installed capacity | 0.25 |
| | | Photoelectric conversion efficiency (SP32) | The conversion efficiency of solar photovoltaic cells | 0.32 |
| | Unit start-stop loss (EU11)<br>processes | | Phased loss estimates for start-stop | 0.21 |
| | Energy-saving generation scheduling (SP1) | Replacement electricity income (EU12) | Marginal income of generating units | 0.20 |
| | Fixed cost compensation (EU13) | | Fixed cost compensation under energy-saving generation dispatching | 0.035 |
| EU | The conversion rate of thermal power fuel (EU21) | | The conversion efficiency of coal fuel consumption for power generation | 0.046 |
| | Power conversion (EU2)<br>effect (EU22) | Power generation conversion | The proportion of regional power generation and power consumption | 0.061 |
| | Power consumption intensity (EU23) | | Electricity consumption per unit | 0.058 |
| | | Byproduct recovery rate (SC11) | The recovery efficiency of by-products in the power generation process | 0.38 |
| SC | Carbon source flow (SC1) | Carbon emission recovery rate (SC12) | | |
| | | | The recovery rate of carbon emission | 0.04 |

| Primary Indicators | Secondary Indicators | Tertiary Indicators | Indicator Interpretation | Weigh |
|---|---|---|---|---|
| | Integrated operation capability (SC2) | Power grid material (SC21) detection capability | Power grid material quality | 0.030 |
| | | Storage cluster throughput (SC22) | Storage cluster throughput capacity of the power supply chain | 0.22 |
| | | Green procurement (SC23) | Green purchasing ability of the power supply chain | 0.13 |
| | | Quality control ability (SC24) | Power Supply Chain Control Capability | 0.28 |
| PG | Energy consumption at the supply and demand side (PG1) | The coal consumption rate of power generation (PG11) | Standard coal consumption per cycle/power generation per cycle | 0.51 |
| | | The coal consumption rate of power generation (PG12) | Standard coal consumption per cycle/power generation per cycle | 0.042 |
| | Power grid construction (PG2) | Smart grid construction (PG21) | Grid load rate | 0.066 |
| | | Grid Loss (PG22) | Grid Line Loss Rate | 0.069 |
| TS | Carbon quota allocation (TS1) | The compact scale of quota allocation (TS11) | The ratio of Total Quota to Total Carbon Emissions of Regional power Enterprises | 0.023 |
| | | Carbon emission data statistics and verification (TS12) | The construction of regional carbon emission data information disclosure platform | 0.024 |
| | Market effectiveness (TS2) | The linkage between Electricity Price and Carbon Market Price (TS21) | The correlation coefficient between regional electricity price and the carbon price | 0.027 |
| | | The volatility of electricity price (TS22) | The volatility of regional electricity price | 0.032 |

| Primary Indicators | Secondary Indicators | Tertiary Indicators | Indicator Interpretation | Weigh |
|---|---|---|---|---|
| | | | | 0.047 |
| Electricity market size (TS23) the regional power market | | | Actual power consumption data of | |

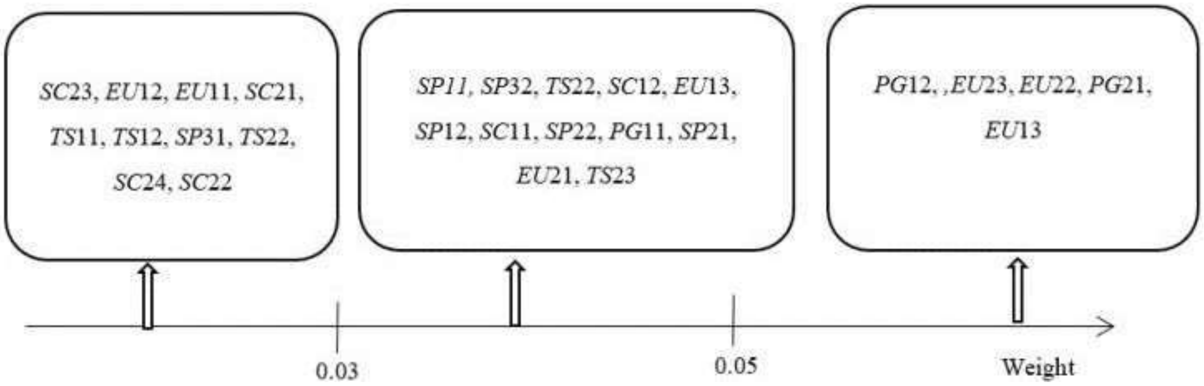
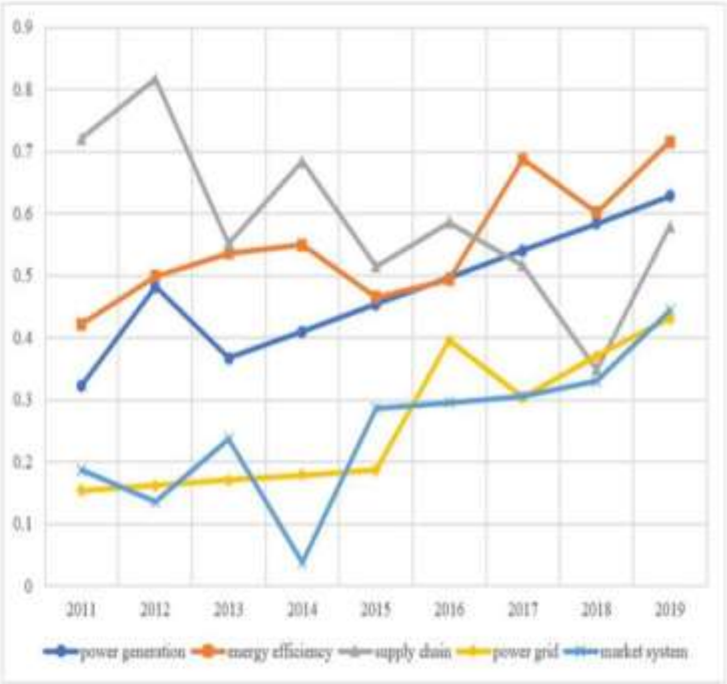
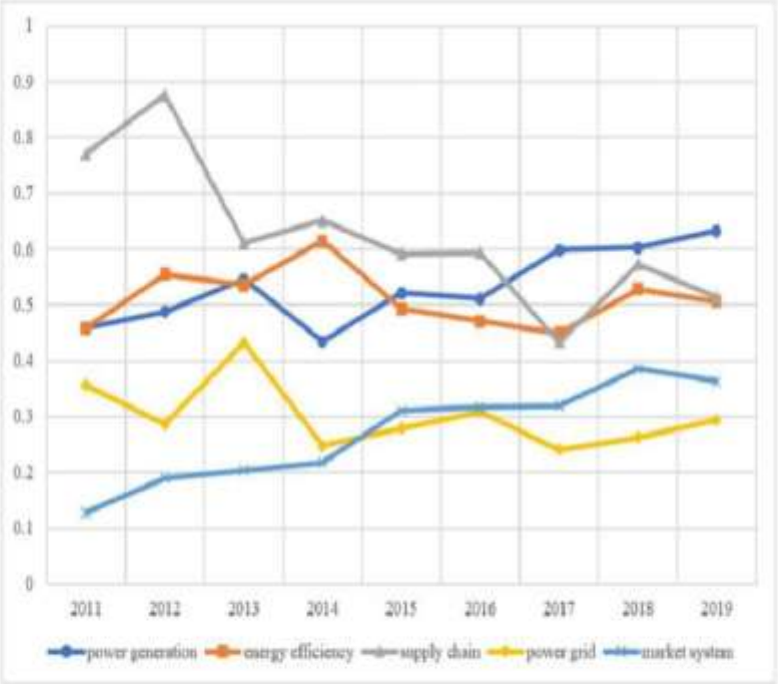


**Fig.4.2:-** Illustrating an abscissa axis of the index system in ranges 0.01 to 0.1.





The CO2 emission data from the power station was extracted using Carbon Intensity API to analyse how the power plant capacity can be reduced to switch to green energy sources of penetrating the grid:

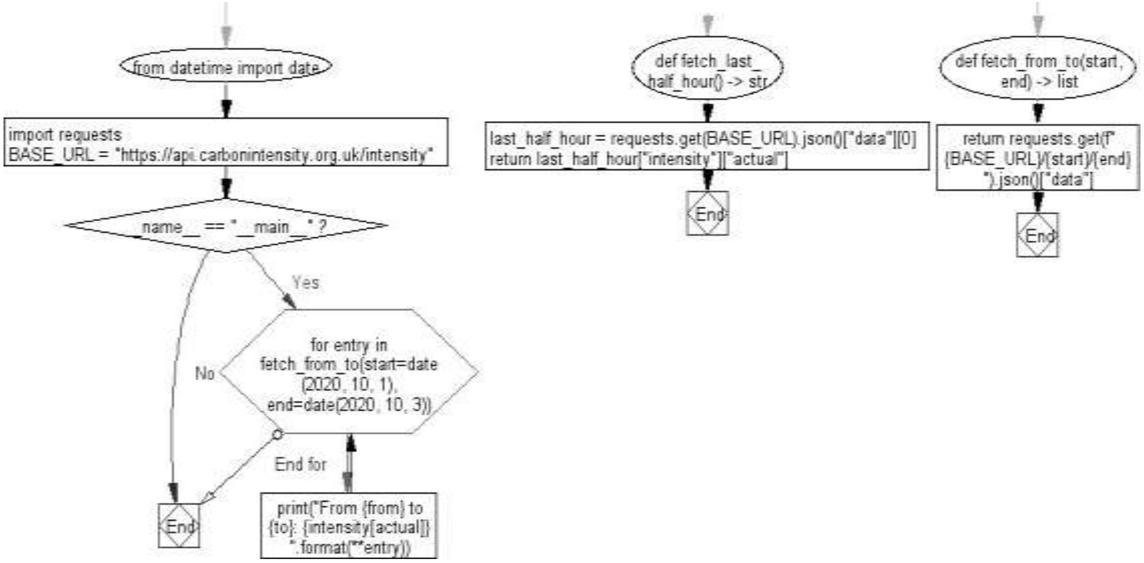


**Fig. 4.5:-** Flowchart indicating the line process of Carbon Intensity API for appending emissions data (Year 2020).

In ETSAP TIAM (Energy Technology Systems Analysis Programme - TIMES Integrated Assessment Model), the Carbon Intensity API (Application Programming Interface) works by providing a standardized interface for accessing and analyzing carbon intensity data within the model framework through the following line process:

1. **Data Collection:** The Carbon Intensity API gathers data on carbon intensity from various sources, such as energy consumption, emissions data, and technological parameters within the model.
2. **Calculation Methodology:** It applies predefined algorithms or methodologies to calculate carbon intensity metrics for different energy technologies, sectors, or regions. These calculations typically consider factors such as emissions per unit of energy produced or consumed.
3. **Integration with TIAM**: The API seamlessly integrates with the ETSAP TIAM model, allowing users to access carbon intensity data directly within the modeling environment. This integration enables users to incorporate carbon intensity considerations into their energy system analysis and decision-making processes.
4. **Customization and Parameters:** Users may have the flexibility to customize parameters or inputs for carbon intensity calculations based on specific scenarios, assumptions, or policy settings. This customization allows for tailored analysis and sensitivity testing within the model framework.
5. **Output and Analysis**: The API generates output data and analysis results related to carbon intensity, which users can use to evaluate the environmental impact of different energy system configurations, policy measures, or technology pathways. This output may include carbon intensity values for individual technologies, sectors, or the overall energy system, as well as visualizations or reports for further interpretation.
6. **Updates and Maintenance:** The Carbon Intensity API may be periodically updated to incorporate new data sources, refine calculation methodologies, or accommodate changes in the model structure. Continuous maintenance ensures the accuracy and reliability of carbon intensity information provided by the API.

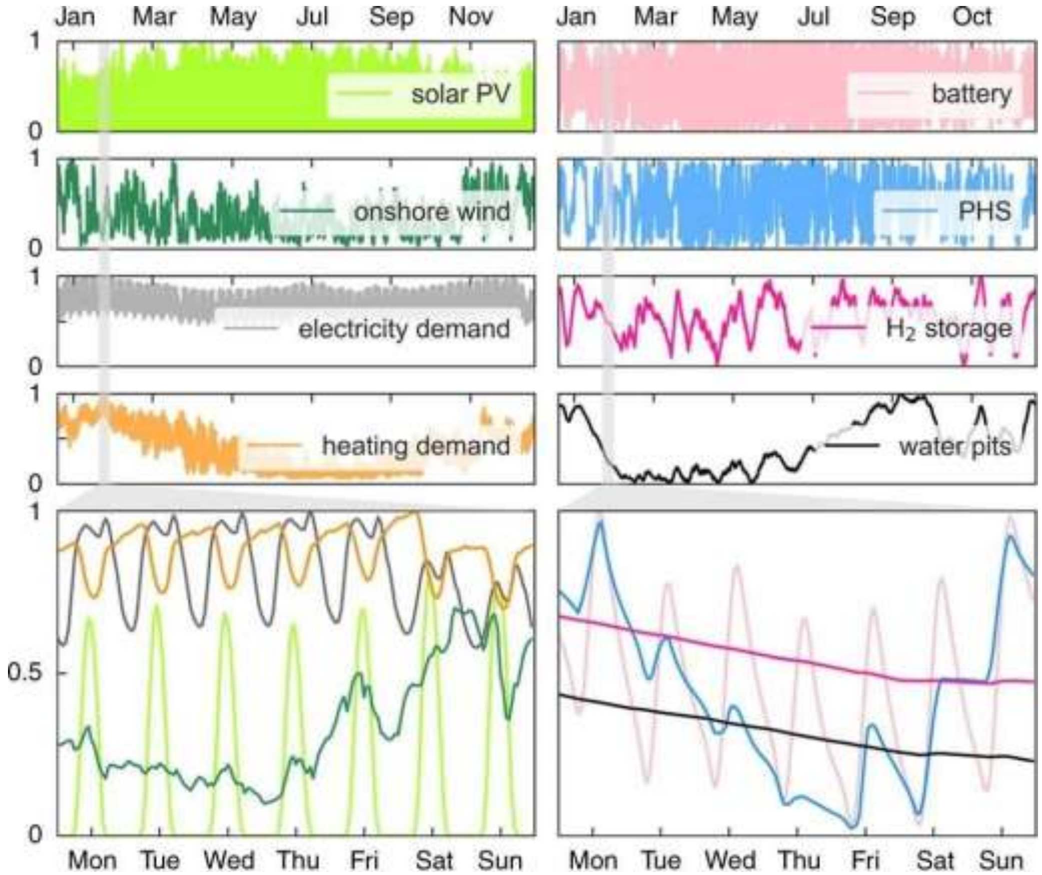


**Fig. 4.6:-** Time series plot in Power BI for the Middle East-aggregated demand, generation and storage technologies dispatch for the Early and Steady path in 2023.

When evaluating the sustainability of each of the seven proposed expansion plans, it is found that none are dominated. Because of this, decision makers must carefully consider the tradeoffs between the proposed expansion plans that rely heavily on CCS (Carbon Capture System) technologies or renewables and nuclear. It is evident that under equal weights, expansion plans with a large deployment of CCS technologies tend to have lower overall sustainability scores.

**Results of the framework model:**

Using the aforementioned model, the possibility of hydrogen and PV Penetration into the grid were analysed by modelling a virtual dataset with the off-plan calculations of the utility demand.

**Hydrogen Energy Penetration:**

The analysis indicates that:

1. Hydrogen emerges as a cost-efficient energy carrier primarily under strict climate change mitigation policies.
2. In the absence of significant reductions in green hydrogen production costs, its adoption is primarily seen in sectors with limited alternative decarbonization options.
3. The demand for hydrogen and the deployment of infrastructure are mainly propelled by advancements in fuel cell technology.

**Solar Photo Voltaic Generation:**

Solar photovoltaic (PV) plays a crucial role in decarbonization efforts due to its dominance in the generation of electricity from non-fossil fuel sources. Achieving a high degree of electrification in various end-use markets is essential for reducing reliance on fossil fuels and minimizing residual carbon emissions. Solar PV, along with other renewable energy sources, is instrumental in this transition by providing clean and sustainable electricity, thus contributing significantly to the overall goal of decarbonization.

The decarbonization pathway outlined in this project offers a strategic blueprint for transitioning to a low-carbon energy system. By leveraging ETSAP LIAM and following a systematic approach, we have developed a comprehensive framework for achieving decarbonization goals effectively. Through data collection, scenario development, and model calibration, we have gained valuable insights into the current state of the energy system and identified opportunities for improvement. Optimization analysis has enabled us to identify cost-effective strategies for reducing carbon emissions while maintaining energy security and affordability.

**Limitations:**

From the modelled data, storage systems cycle between charging and discharging to fulfil various grid service needs, sometimes exhausting their energy reserves. Monitoring the state of charge enables grid operators to assess whether storage systems have adequate power to respond promptly during periods of low wind and solar generation. Moreover, many models fail to address the complex supply chain challenges associated with manufacturing energy storage technologies.

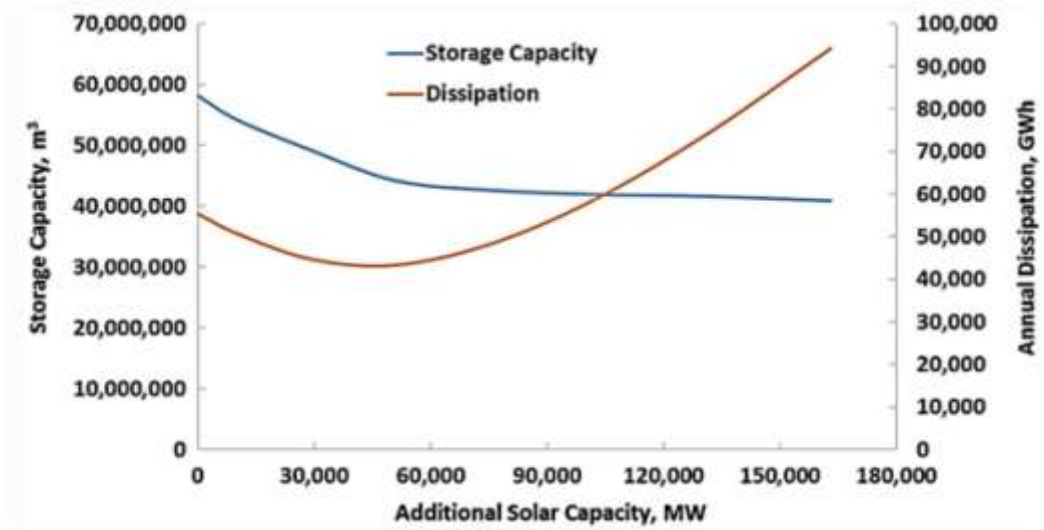


**Fig. 4.7:-** Combinations of additional wind and solar energy power infrastructure needed for the decarbonization of the system visualized using Power BI

When the model is permitted to optimize transmission capacities post-2030 alongside generation and storage assets, the resulting optimal configuration at the conclusion of the analysis reveals a transmission volume roughly three times greater than that of 2030. This augmentation in interconnections aids in mitigating variability in solar patterns, consequently amplifying the optimal capacities for onshore PV generation. Moreover, the presence of reinforced interconnections diminishes the required energy capacity for hydrogen storage by aiding in the balancing of PV Generation.

Challenge Opportunities

Improving temporal resolution Enhancing spatial resolution Increasing sector disaggregation Uncertainty quantification
Transparency- Open energy modeling Addressing
increasing complexity of future energy systems
Integration social aspects
Capturing features for developing countries
Data quality and availability Renewable Penetration

Enhancing resolution by utilizing shorter time intervals (hours recommended) to capture intermittent renewable supply
Including more nodes to represent diverse geographic zones, distributed energy, and transmission complexities
Disaggregating industrial sector for energy management and efficiency modeling
Incorporating uncertainty assessment methods such as Monte Carlo simulation, scenario analysis, robust optimization
Implementing open data methodologies and models with comprehensive documentation of the modeling process
Integrating with power system models; Modeling various supply-demand balance options including energy storage, demand-side management, and smart grids

Linking with macroeconomic or sectoral models;

Including modeling capabilities for supply shortages, rural-urban divisions, informal economies, and energy service subsidies

Promoting data acquisition and real-time monitoring projects, open data repositories; Using simulation models to generate synthetic data.
Allow microgrid expandability criterion mandatory in future developments.

**Table B:-** Results of the predicted data from the ETSAP-TIAM model after simulating the microgrid in Power BI and validating the net-carbon capture (CCS).

## Conclusion:-

The pursuit of decarbonization within the Dubai Electricity and Water Authority (DEWA) grid necessitates comprehensive planning and evaluation of key factors influencing power decarbonization. Through the construction of an evaluation index system, crucial metrics such as grid load rate, grid line loss rate, power generation conversion efficiency, and power consumption intensity have been identified as pivotal in driving the decarbonization process. However, attention must also be directed towards addressing the intermittency of renewable energy sources like wind and solar, as well as adapting to changes in demand patterns.

The findings underscore the importance of advancing technological innovation and upgrading infrastructure in the pursuit of low-carbon development within the DEWA grid. While the overall development level of low-carbon initiatives in the power industry shows a positive trend, regional disparities necessitate tailored strategies. The eastern region may prioritize energy efficiency enhancements, the central region should focus on smart grid upgrades, and the western region should strengthen power supply chain construction.

Looking ahead, the establishment of a national carbon emissions trading market and power market, supported by both market mechanisms and government initiatives, emerges as a crucial pathway towards realizing low-carbon development within the DEWA grid. Additionally, optimization of power supply configurations, enhancement of market operations, and improved coordination mechanisms between transmission and consumption will be essential in optimizing the operation of the power system and facilitating decarbonization.

Moreover, there is a need for further exploration of strategies to maximize the utilization of renewable energy sources, reduce costs, enhance efficiency, and accurately measure the decarbonization contributions of the power industry.

## References:-

1. B. Kroposki, “Achieving a 100% renewable grid: operating electric power systems with extremely high levels of variable renewable energy” IEEE Power Energy Mag., 15 (2) (2017), pp. 61-73
2. D. Gielen, et al., ‘The role of renewable energy in the global energy transformation’, Energy Strategy Reviews, 24 (2019)
3. P.D. Martini, et al. ‘Coordination of Distributed Energy Resources; International System Architecture Insights for Future Market Design’, Newport Consortium (2018)
4. C.F. Heuberger, N. Mac Dowell, “Real-world challenges with a rapid transition to 100% renewable power systems
5. Khalilzadeh S., Nezhad A.H. Utilization of waste heat of a high-capacity wind turbine in multi effect distillation desalination: Energy, exergy and thermoeconomic analysis. Desalination Int. J. Sci. Technol. Desalt. Water Purif. 2018
6. Fragkos P., Tasios N., Paroussos L., Capros P., Tsani S. Energy system impacts and policy implications of the European Intended Nationally Determined Contribution and low-carbon pathway to 2050. Energy Policy. 2017
7. Bodal E.F., Mallapragada D., Botterud A., Korpås M. Decarbonization synergies from joint planning of electricity and hydrogen production: A Texas case study. Int. J. Hydrogen Energy. 2020.