ATTEYA, A.I., ALI, D. and HOSSAIN, M. 2022. Developing a capacity sizing and energy management model for a hybrid photovoltaic-hydrogen grid-connected building scenario. Presented at the 2022 All-energy exhibition and conference: low carbon heating and cooling, 11-12 May 2022, Glasgow, UK.

Developing a capacity sizing and energy management model for a hybrid photovoltaic-hydrogen grid-connected building scenario.

ATTEYA, A.I., ALI, D. and HOSSAIN, M.

2022

ROBERT GORDON UNIVERSITY ABERDEEN

21 YEARS OF ALL-ENERGY

ALL-ENERGY EXHIBITION AND CONFERENCE 2022

Dcarbonise EXHIBITION AND CONFERENCE 2022

1

Title: "Developing a Capacity Sizing and Energy Management Model for a Hybrid Photovoltaic-Hydrogen Grid-connected Building Scenario"

Presented by: Ayatte I. Atteya

Supervised by: Dr. Dallia Ali - Dr. Mamdud Hossain

School of Engineering, Robert Gordon University (RGU)

Outline

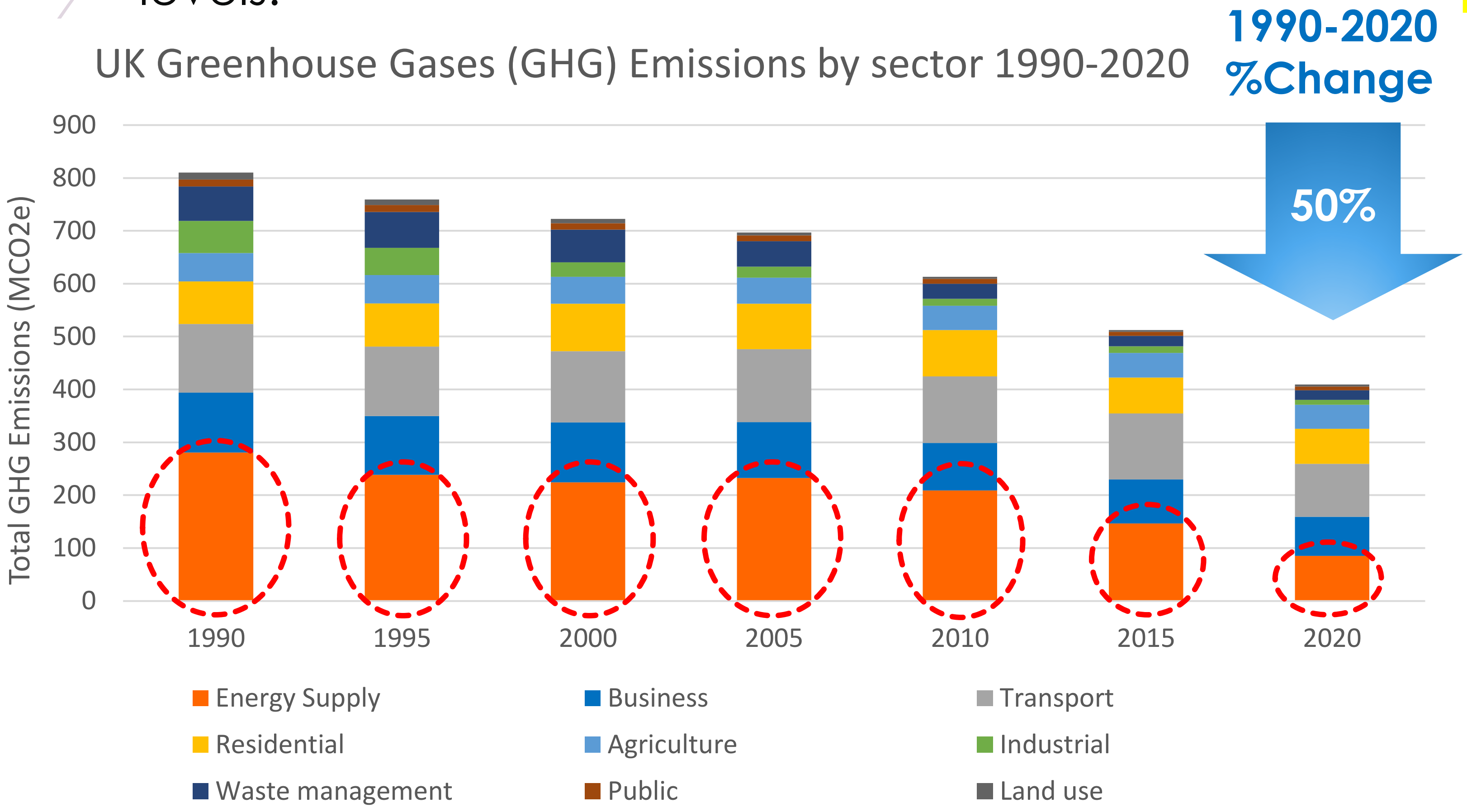
- Introduction
- Green Hydrogen Energy Storage
- Rationale of the proposed Research
- The proposed hybrid PV-H2 system for grid-connected buildings
- Case Study
- Capacity sizing of the proposed system components
- Energy Management Model of the proposed system components
- Simulation Results
- Conclusion

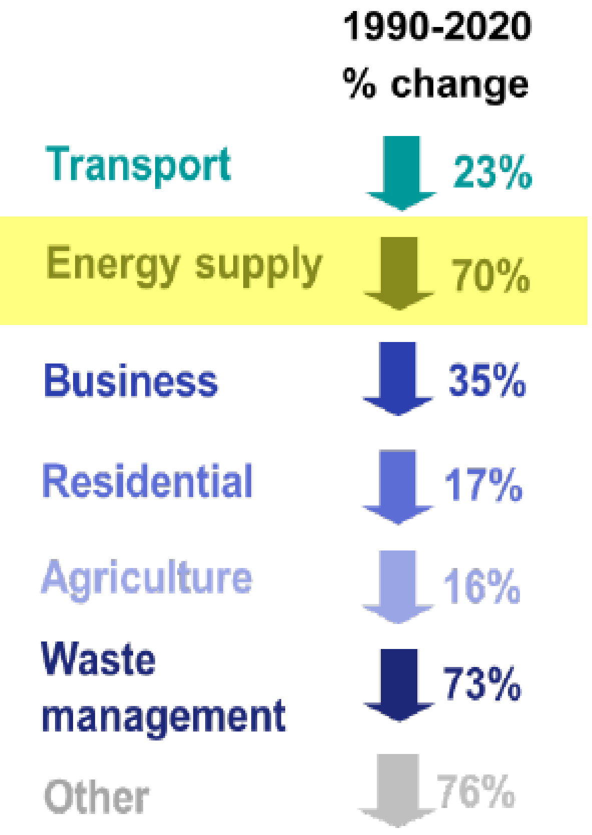
Introduction

- In June 2019, the parliament passed a new legislation requiring the UK to bring down all greenhouse gas emissions (GHG) by **100% by 2050**, compared to1990 levels.

The energy supply sector has accounted for 70% of the overall reduction in UK GHG emissions since 1990.

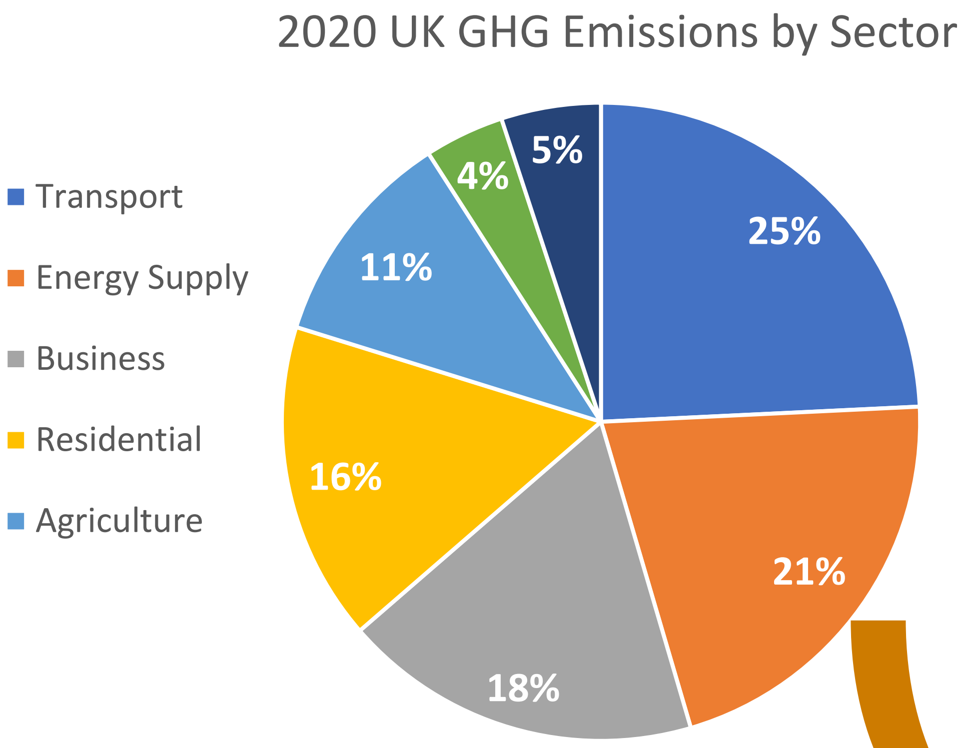
UK Greenhouse Gases (GHG) Emissions by sector 1990-2020

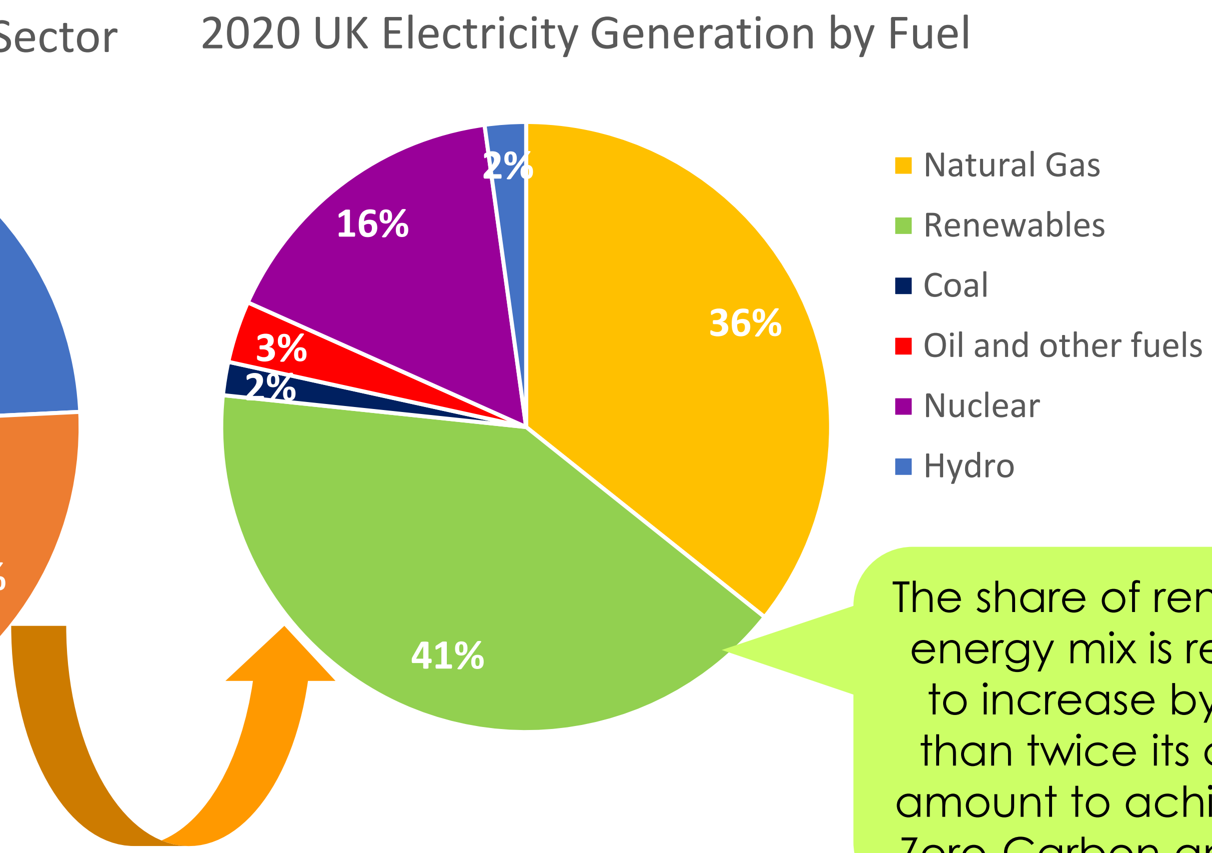




Introduction

- **Energy Supply** Sector has been the **second largest contributor** to GHG emissions in 2020 after transport sector, constituting 21% of total GHG emissions.





The share of renewable energy mix is required to increase by more than twice its current amount to achieve the Zero-Carbon ambition.

ROBERT GORDON UNIVERSITY ABERDEEN

Introduction

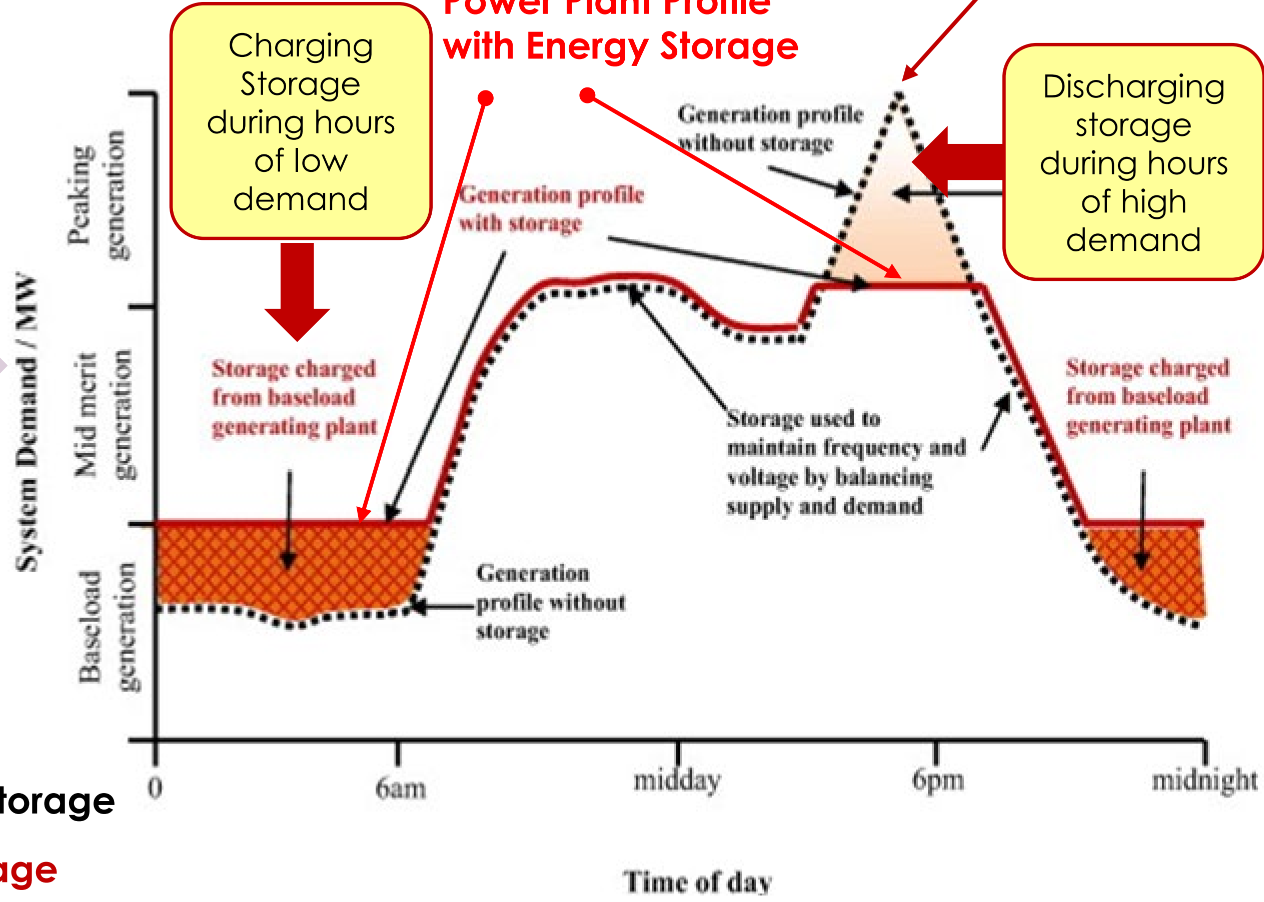
- The admission of renewable energy systems into the grid **is subject to significant variability due to their intermittency**, requiring central generations to cover any transient variation between renewable power input and consumer demand.

Suggested Solution

Integration of Energy Storage Systems

Fossil-fuel spinning reserves running without energy storage

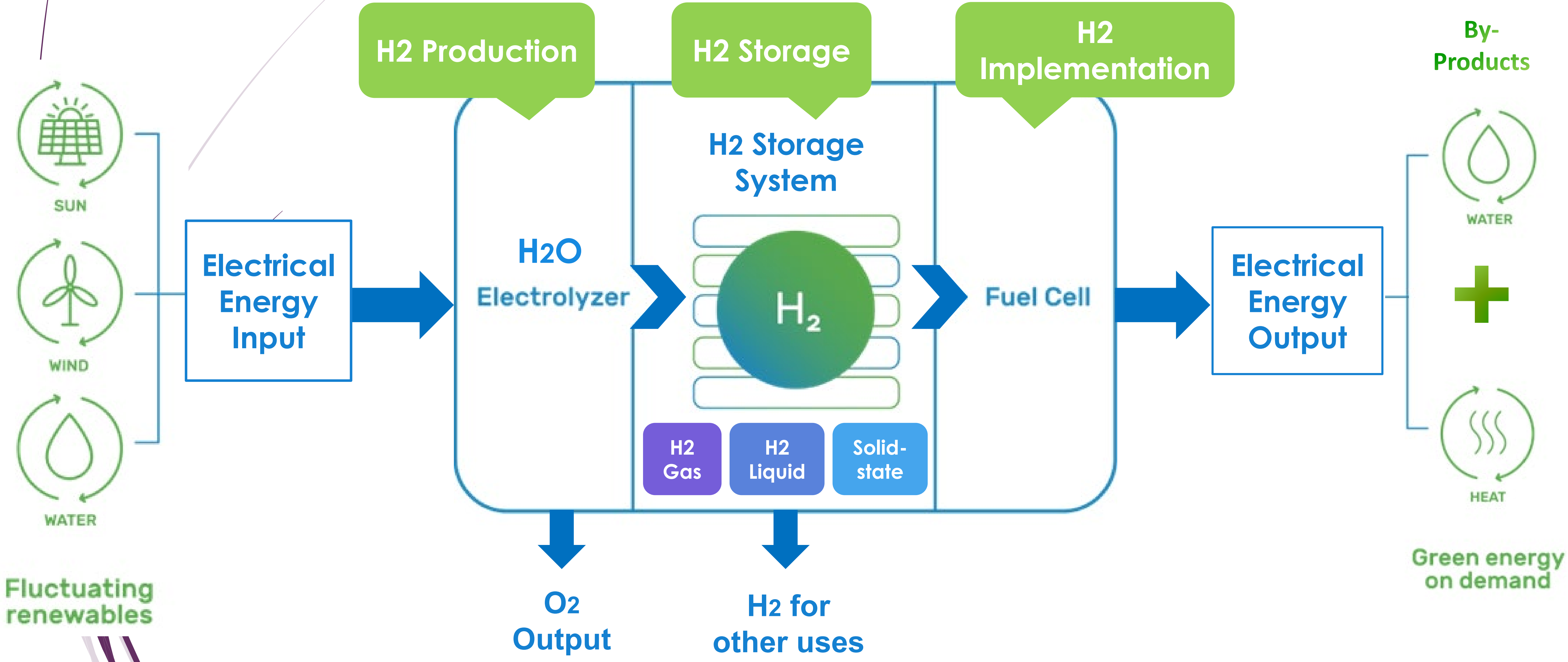
Improvement of Power Plant Profile with Energy Storage



------ **Generation profile without energy storage**

—— **Generation profile with energy storage**

Green Hydrogen Energy Storage Systems



Rationale of the Proposed Research

The integration of Renewables into Electrical Power Systems brings major technical challenges which can be addressed by integrating Green Hydrogen Energy Storage (HES); however, integrating HES requires:

System Sizing

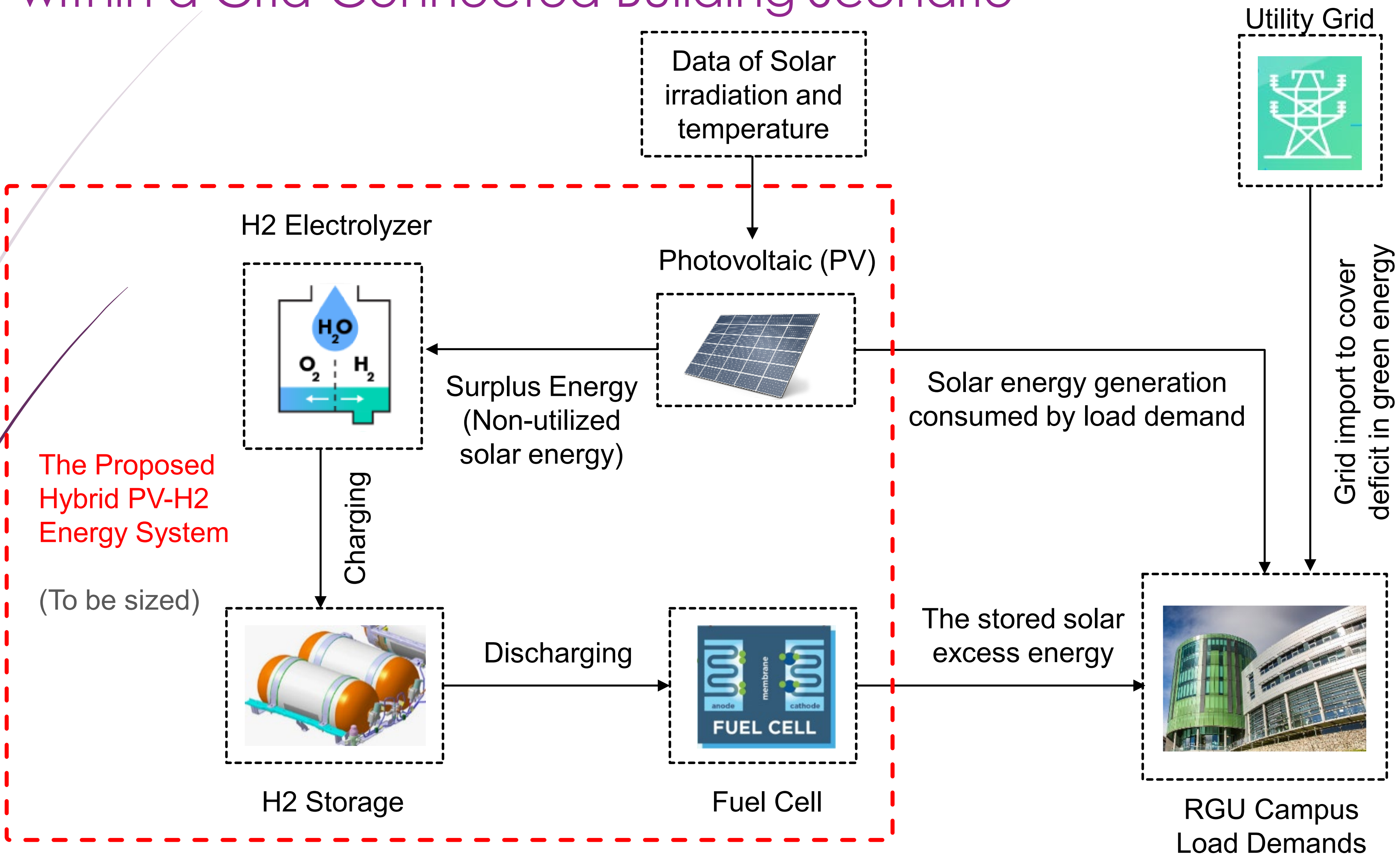
- Meeting the energy demands
- Mitigating the intermittency of renewable energy
- Minimizing the GHG emissions

Operation Scheduling

- Scheduling the operation of the hydrogen system components with other parts of the electrical system

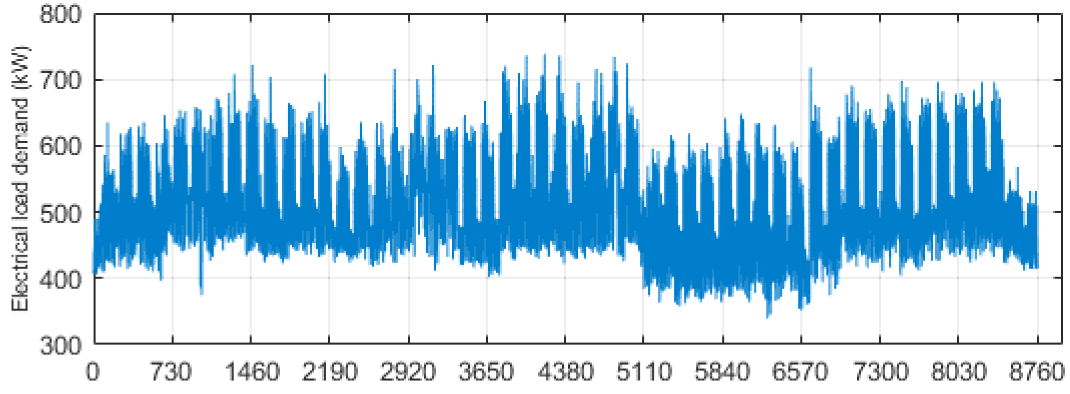
ROBERT GORDON UNIVERSITY ABERDEEN

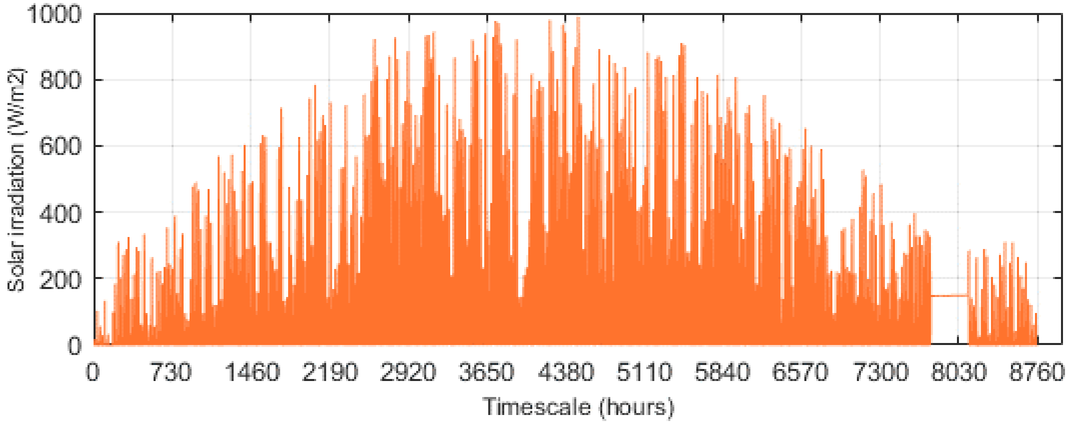
The Proposed Hybrid Photovoltaic-Hydrogen Energy System within a Grid-Connected Building Scenario

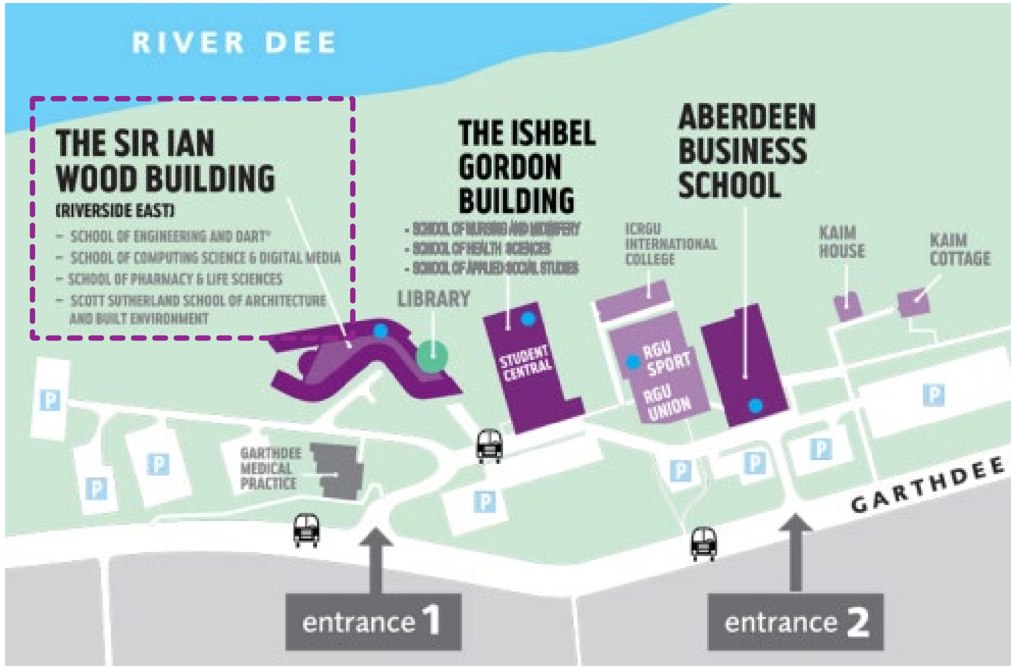


Case Study: Sir Ian Wood Building (SIWB) – RGU Campus

- The proposed system sizing and energy management modelling has been developed for SIWB (as case study) based on its actual hourly load demand profile for the year 2020/2021



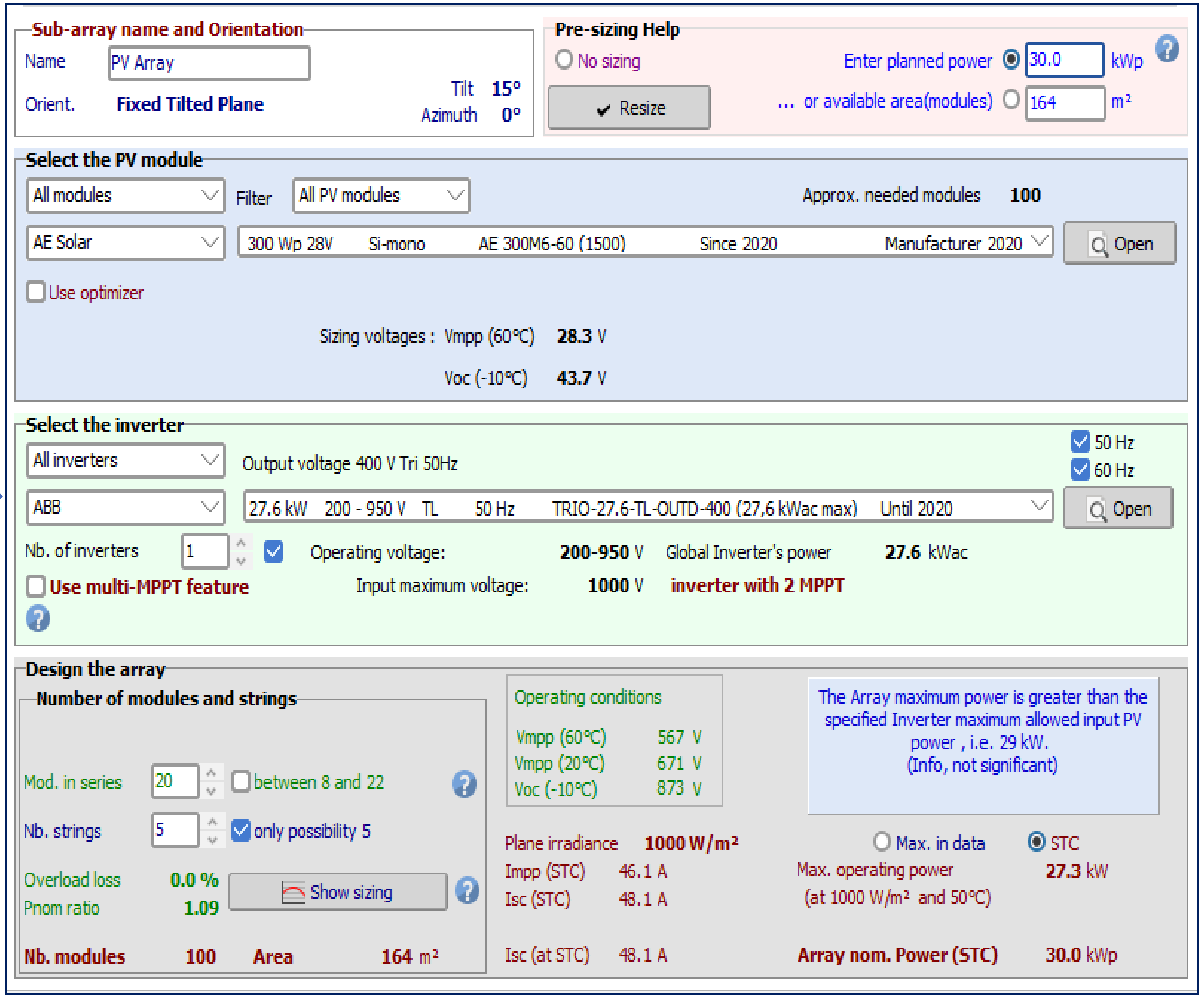




Parameter	Rating
Average Demand	515.8 kW
Peak Demand	738 kW
Minimum Demand	340 kW
Total Annual Demand	4.518 GW

Simulating the Building Currently Installed PV Capacity

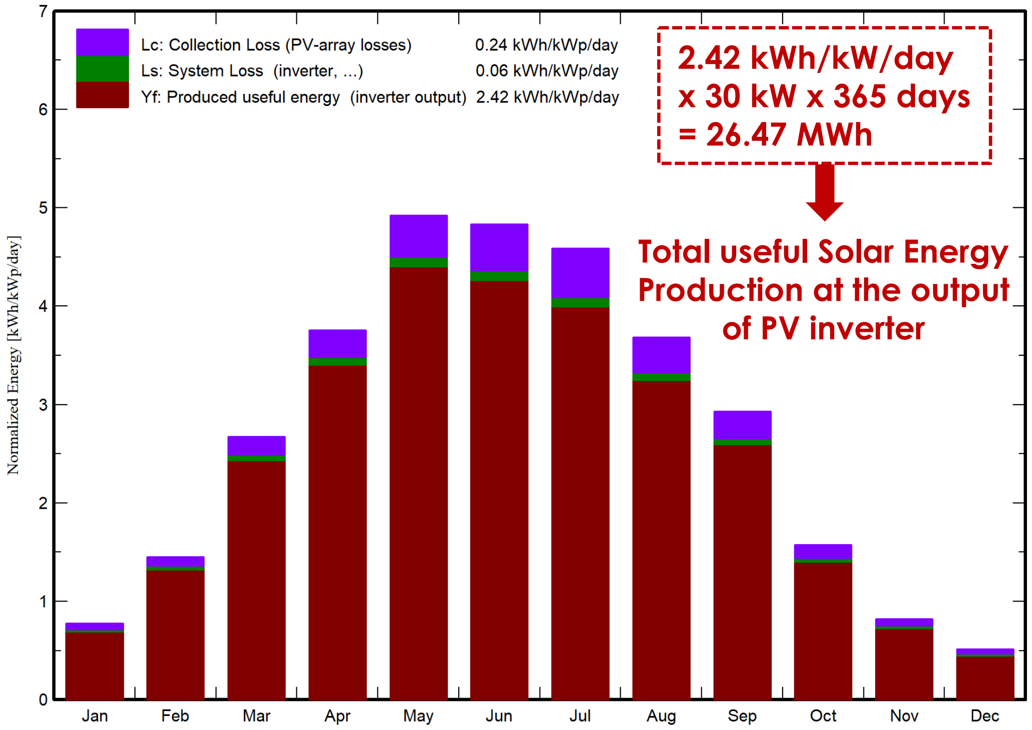
Design Specifications of PV Facility currently installed in RGU Campus	
Panel Orientation	Facing South (Azimuth: 0°)
Pitch Angle	15°
Solar PV Module Type	SI-Mono X Neon 300 W PV Panel
Number of PV panels installed	100
Total PV Installed Capacity	30 kW
Inverter Type	Power-One TRIO-27.6TL S2X Inverter
Number of installed inverters	1



ROBERT GORDON UNIVERSITY ABERDEEN

Simulating the Building Currently Installed PV Capacity

Normalized productions (per installed kWp): Nominal power 30.0 kWp



Analysis of PV Facility currently installed in RGU	
Total Solar Energy Supplied to Load Demand	26.47 MWh
Total Load Energy Consumption	4518 MWh
% Solar Energy Supplied to Load Demand	0.58 %

Monthly Load Energy consumption

Solar Energy fed to load demand

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_User MWh	E_Solar MWh	E_Grid MWh	EFrGrid MWh
January	15.5	10.60	4.00	24.1	22.6	0.668	376.0	0.645	0.000	375.4
February	30.2	19.20	3.80	40.7	38.6	1.144	360.0	1.113	0.000	358.9
March	68.0	37.70	5.40	83.0	79.5	2.318	389.0	2.263	0.000	386.7
April	102.0	64.00	7.30	112.7	108.4	3.133	364.0	3.062	0.000	360.9
May	144.2	76.30	9.90	152.5	147.4	4.187	391.0	4.095	0.000	386.9
June	140.9	79.60	12.40	145.0	140.1	3.930	386.0	3.840	0.000	382.2
July	136.7	72.30	14.80	142.3	137.4	3.805	404.0	3.716	0.000	400.3
August	105.5	59.70	14.40	114.2	110.0	3.093	354.0	3.022	0.000	351.0
September	74.3	39.60	12.10	88.0	84.4	2.393	349.0	2.338	0.000	346.7
October	38.7	24.30	9.30	48.8	46.5	1.342	377.0	1.306	0.000	375.7
November	16.8	11.90	6.30	24.6	23.1	0.679	381.0	0.656	0.000	380.3
December	9.6	6.90	3.90	16.0	14.8	0.437	387.0	0.418	0.000	386.6
Year	882.4	502.09	8.66	991.7	952.9	27.128	4518.0	26.473	0.000	4491.5

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_User	Energy supplied to the user
T_Amb	Ambient Temperature	E_Solar	Energy from the sun
GlobInc	Global incident in coll. plane	E_Grid	Energy injected into grid
GlobEff	Effective Global, corr. for IAM and shadings	EFrGrid	Energy from the grid

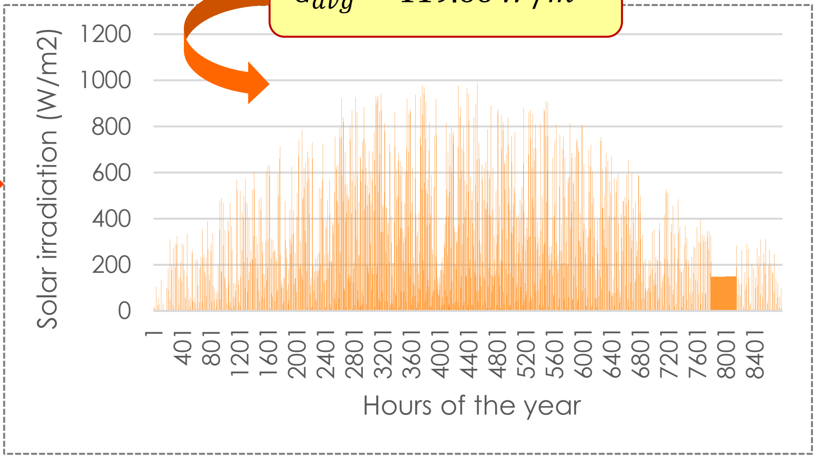
Sizing of the Proposed PV System Capacity

- The size of the proposed PV capacity can be calculated based on the PV capacity factor, defined as the percentage of the average output power from the PV to the rated power of PV module:

$$CF_{PV} = \frac{P_{PV}}{P_{PV\ rated}}$$

$$P_{PV} = P_{avg\ load} = 515.8\ kW$$

$G_{avg} = 119.66\ W/m^2$



PVGIS Data of Hourly Solar Irradiation over one-year

The PV capacity factor (CF_{PV}) can be estimated by measuring the ratio of average actual solar irradiation to the solar irradiation at Standard Test Conditions ($G_{STC}= 1000\ W/m^2$)

$$CF_{PV} = \frac{G_{avg}}{G_{STC}} = \frac{119.66}{1000} = 11.966\%$$

Thus;

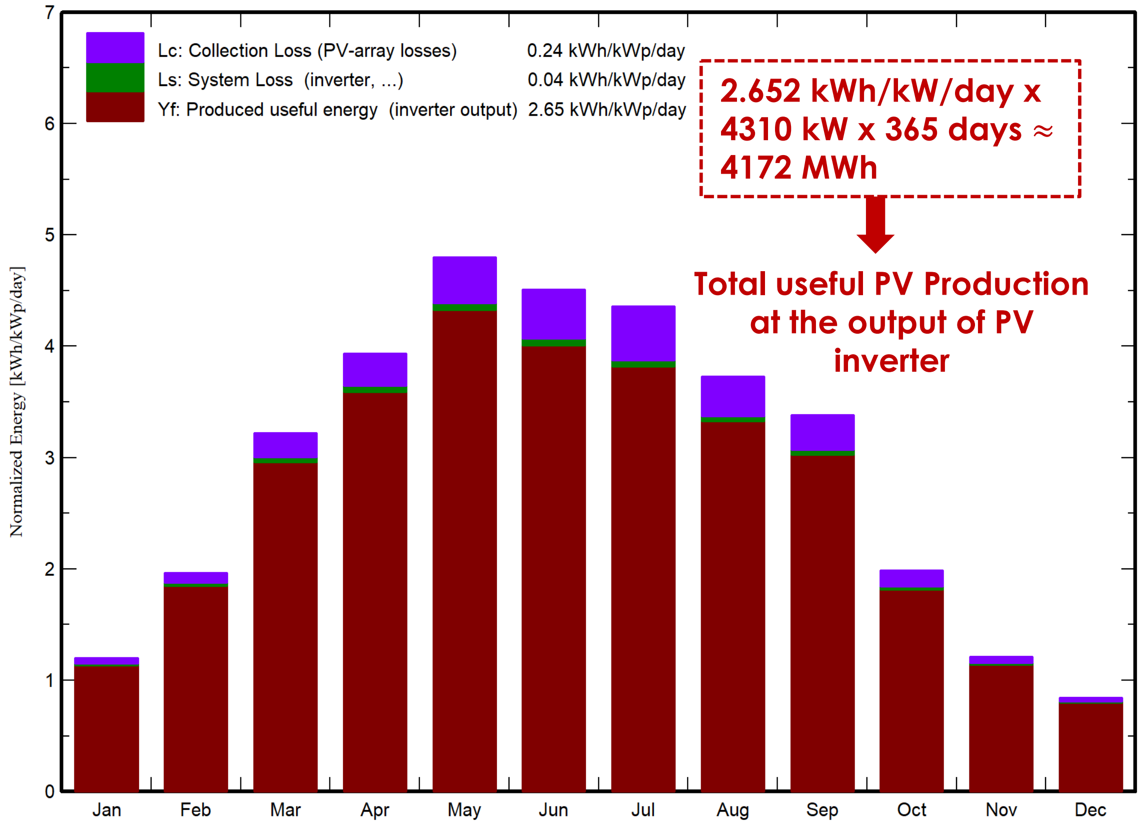
$$P_{PV\ rated} = \frac{P_{PV}}{CF_{PV}} = \frac{515.8}{0.11966} = 4310\ kW = 4.31\ MW$$

Proposed PV Installed Capacity

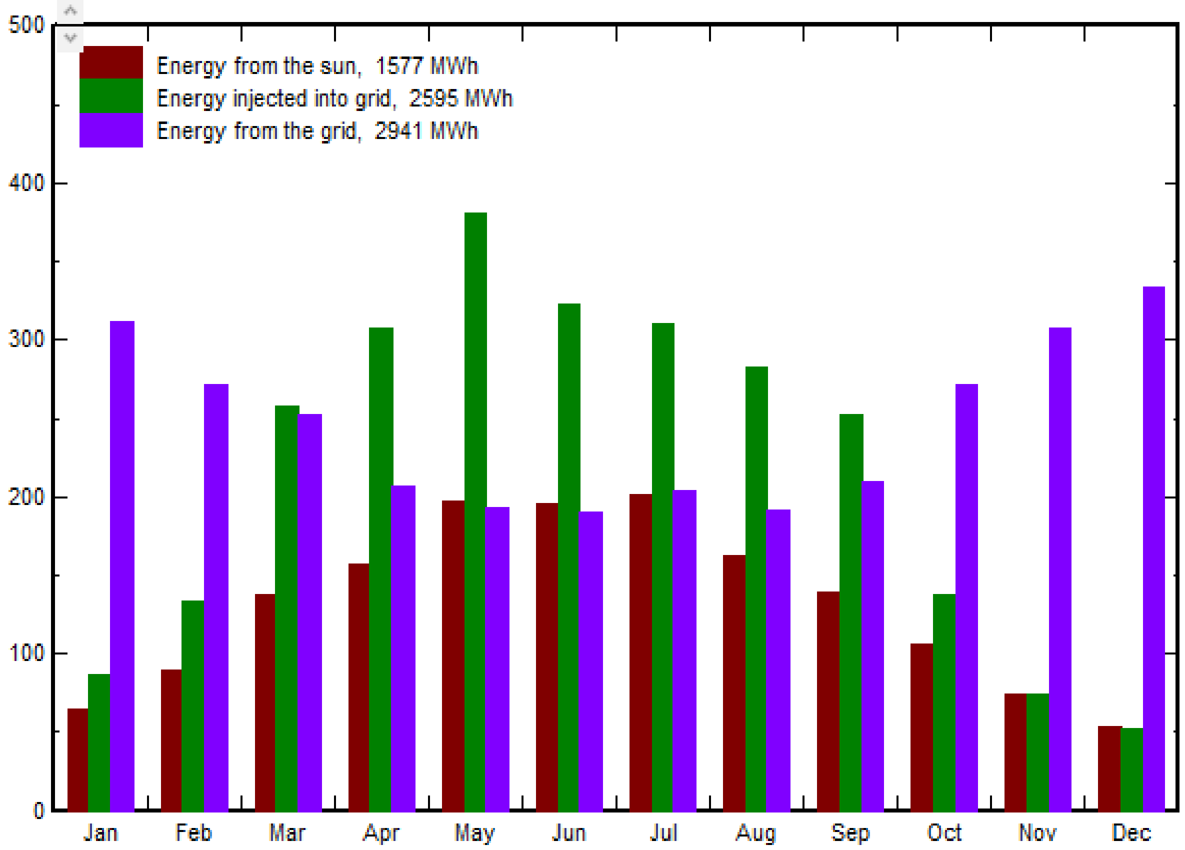
Modelling and Simulation of the Proposed PV System Capacity with no H2 Energy Storage

PVSyst Simulation Results - Monthly Solar energy production by the proposed PV capacity

Normalized productions (per installed kWp): Nominal power 4310 kWp

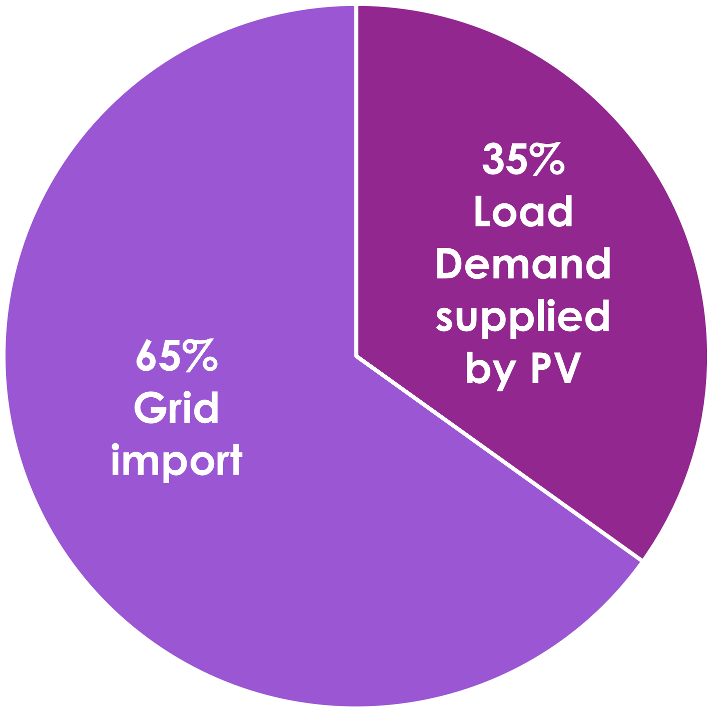


PVSyst Simulation Results – Performance of the proposed grid-connected PV capacity in feeding load demands with no H2 energy storage

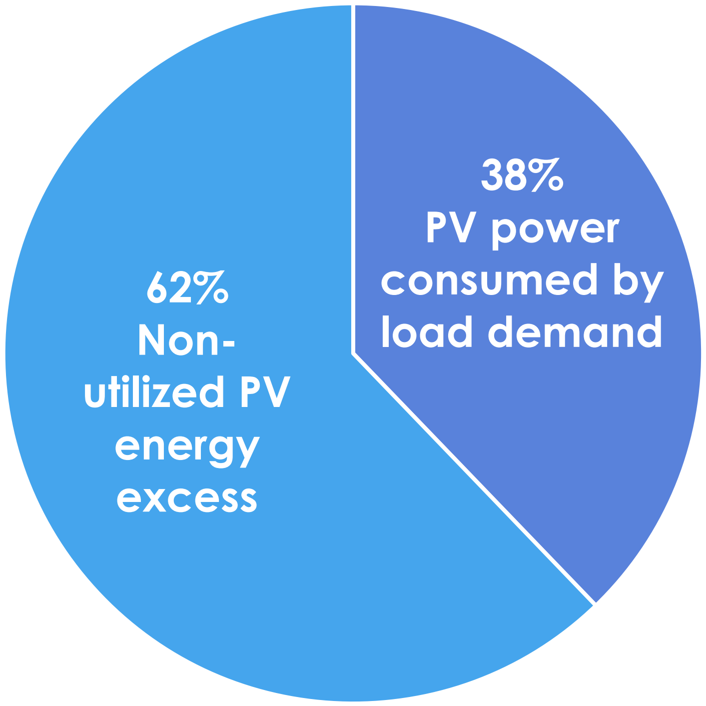


Analysis Results of the Proposed PV System Capacity with no H2 energy Storage

Annual Contribution of the proposed grid-connected PV System in feeding load demands



Annual Utilization of the proposed PV system capacity



Sizing of the Proposed H2 Electrolyser

- The electrolyser can be sized as 50% of the proposed PV capacity to compensate for the level of underutilization during the hours of low availability of solar energy.

$$P_{ele\ rated} = 0.5 \times P_{PV\ rated}$$

$$= 0.5 \times 4.31\ MW = 2.155\ MW$$

NEL A1000 H2 electrolyser (A-Series stacked together)

SPECIFICATIONS	A1000
Net Production Rate	600-970 Nm^3/h
Production Capacity Dynamic Range	15-100% of flow range
Power Consumption at Stack[1]	3.8-4.4 kWh/Nm^3
Purity – with optional purification	99.99-99.999%
O_2-Content in H_2	< 2 ppm v
H_2O-Content in H_2	< 2 ppm v
Delivery Pressure	1–200 barg
Dimensions	
Footprint	~225 m^2
Container 1 – W x D x H	NA
Container 2 – W x D x H	NA
Container 3 – W x D x H	NA
Ambient Temperature	5-35° C
Electrolyte	25% KOH aqueous solution
Feed Water Consumption	0.9 l/Nm^3

Electrolyser Capacity Range

$$= (3.8 - 4.4)\frac{kWh}{Nm^3} \times (600 - 970)\frac{Nm^3}{h}$$

$$= (2.28 - 4.27)\ \text{MW}$$

Satisfying the proposed Size of H2 Electrolyser

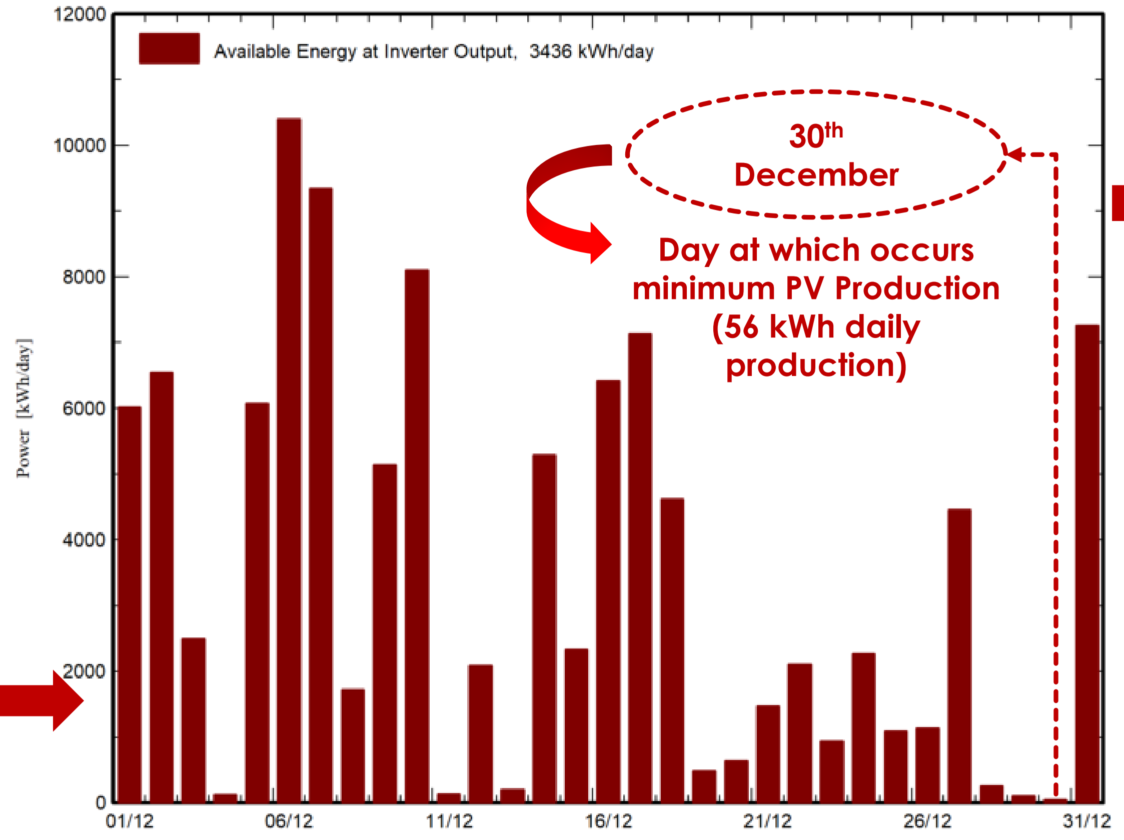
Parameter	Rating
Average H2 Electrolyser Capacity	3.275 MW
Average H2 Volume Production	785 Nm^3/h
Average H2 mass Production	70.7 kg/h
H2 Mass Flow Rate per unit capacity	0.0216 $kg/h/kW$
H2 Electrolyser Target Pressure	200 bar

Sizing of the Proposed H2 Fuel Cell

- The H2 fuel cell has been sized to cover the maximum power deficit that can occur by the proposed PV capacity during the hours of minimum solar production.

	EOutInv MWh
January	151.3
February	223.1
March	395.7
April	464.1
May	578.0
June	518.5
July	510.1
August	444.4
September	391.2
October	242.6
November	147.1
December	106.5
Year	4172.6

PVSyst Simulation Results of Solar Energy Production at the output of PV Inverter during the month of December



Comparison of Solar Energy output at PV inverter and Actual Load Demand during 30th December

A 500-kW closest standard size of fuel cell capacity can be considered, enough to cover the average load demand during the day of min PV production

Sizing of the Proposed H2 Storage Tank

- Based on the maximum permissible working pressure of the selected H2 electrolyser (200 bar), a BOC Manifold 15-Cylinder Pallet (MCP) with the following specifications can be selected:

Manifolded 15 cylinder pallet (MCP)	MCP contents volume (m^3)† (Volume of H2 tank)	Maximum filled pressure at 15°C (bar) (Target Pressure)	Approx. dimensions (H X W X D)‡ - heights are given to centre of typical valve outlet (m)	Approx. gross MCP weight (kg) (Maximum Storage Capacity)
WL	132.00	200	1.85 x 1.29 x 0.84	1331

The suitability of the selected H2 tank is verified through the thermodynamic model of H2 accumulation inside the tank, considering pressure build-up and pressure decrease during charging and discharging processes of H2 tank over the year.

ROBERT GORDON UNIVERSITY ABERDEEN

Sizing Summary of the Proposed Hybrid PV-H2 Energy System

Component		Rating
PV System	Proposed Capacity	4.31 MW
	PV Modules	14368 Modules, 300 W each
	Modules connection	449 strings x 32 in series
	PV inverters	4 units, 1000 kW each
H2 Electrolyser	Rated Capacity	3.275 MW
	H2 Mass Flow Rate	0.0216 kg/h/kW
	Target Pressure	1-200 bars
H2 Fuel Cell	Rated capacity	500 kW
H2 storage tank	Tank Volume	132 m^3
	Mass Storage Capacity	1331 kg
	Target Pressure	200 bars

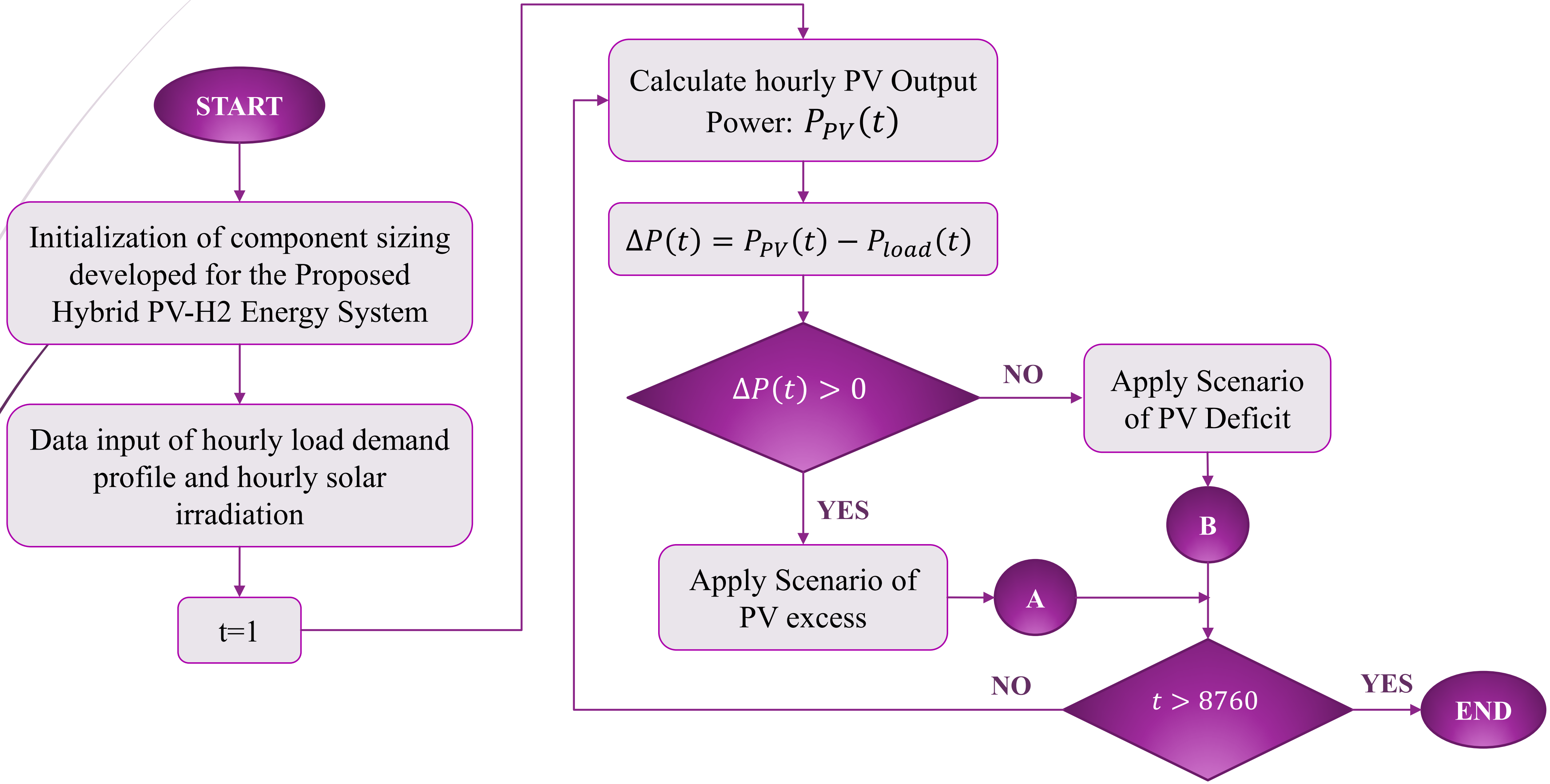
MATLAB

Energy Management Model

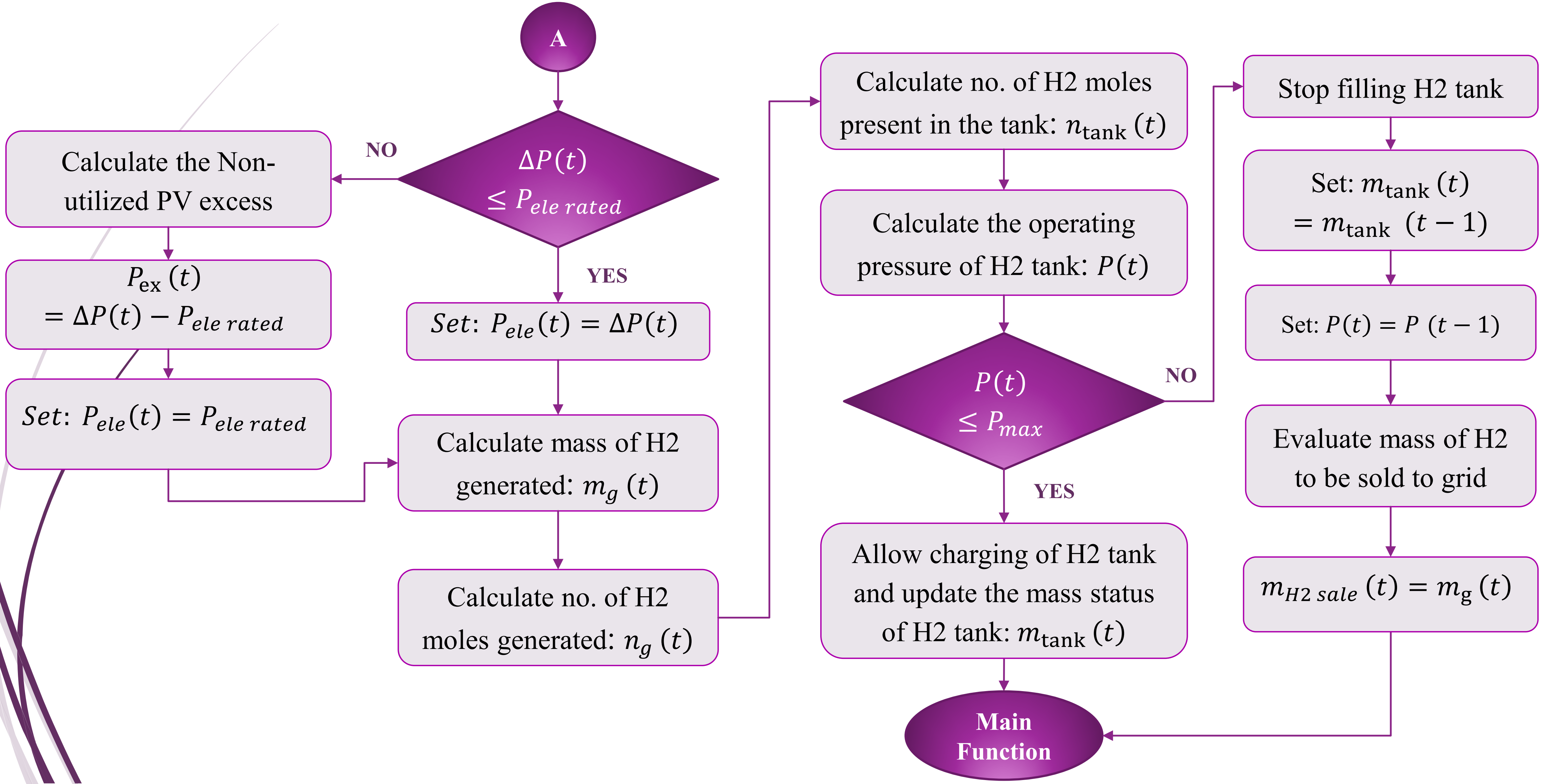
Running on an hourly-basis over the year

To schedule the operation of proposed components and the utility grid in feeding the building demands

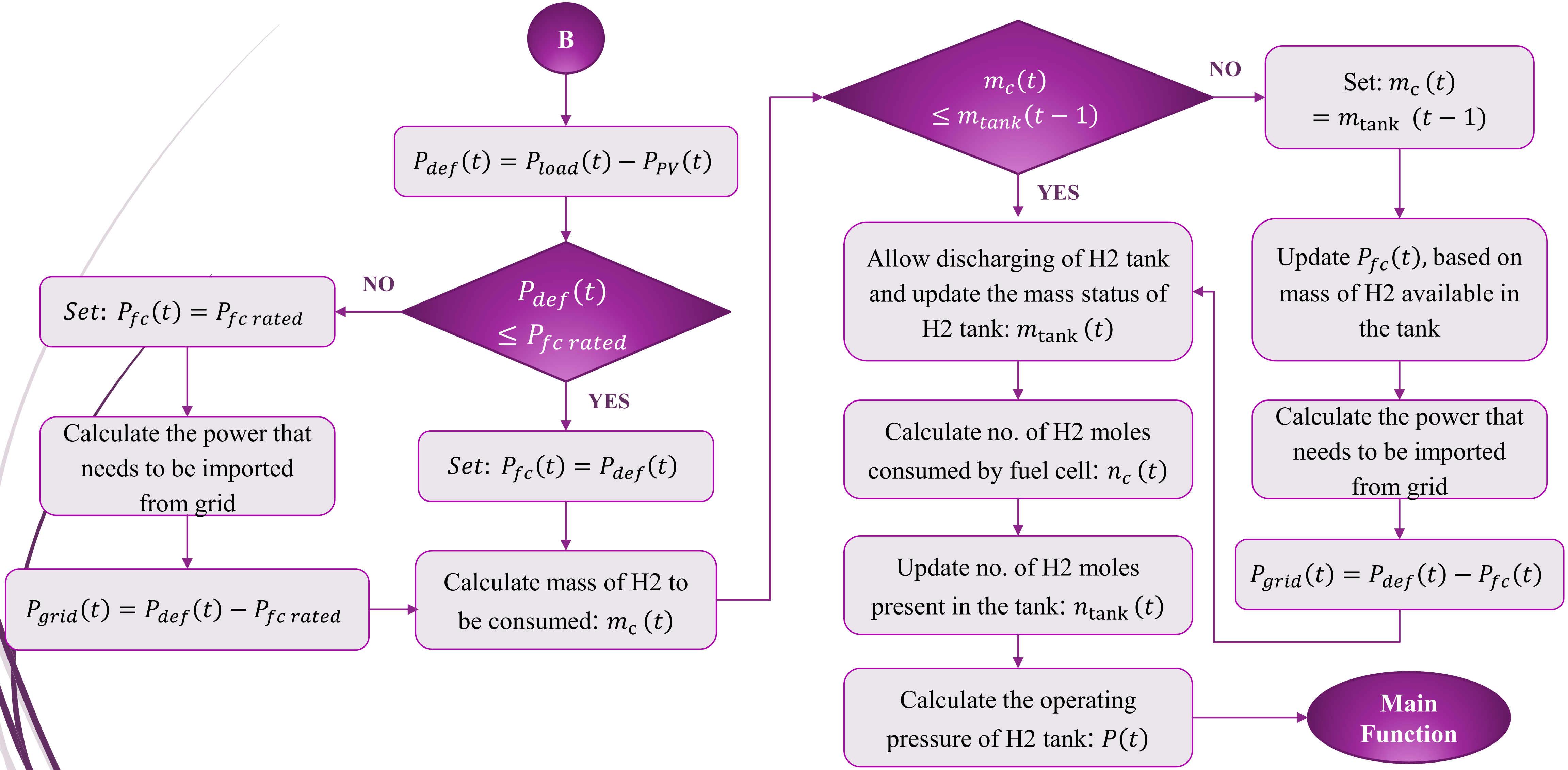
Energy Management Model – Flowchart



Energy Management Model – Scenario of PV Energy Excess



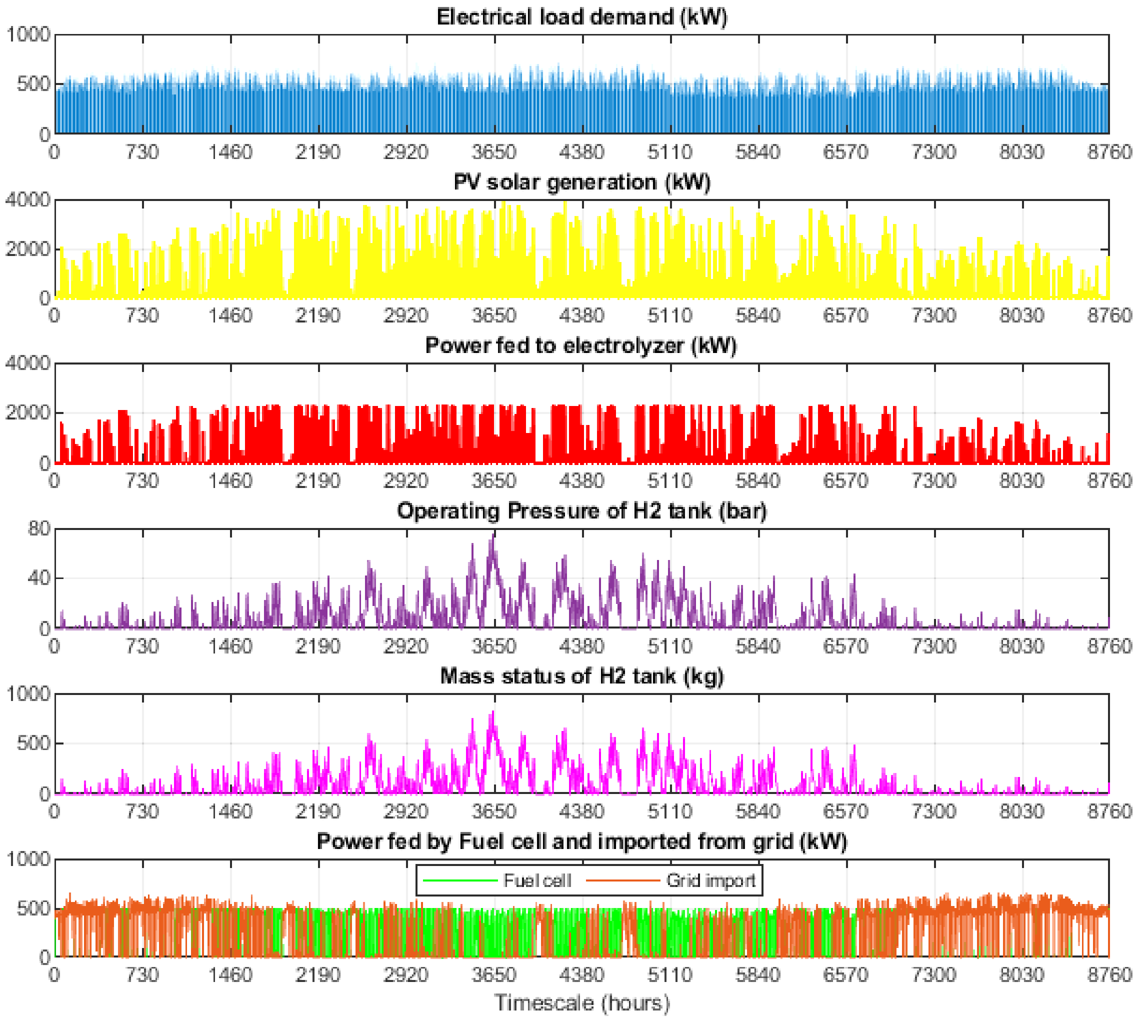
Energy Management Model – Scenario of PV Energy Deficit



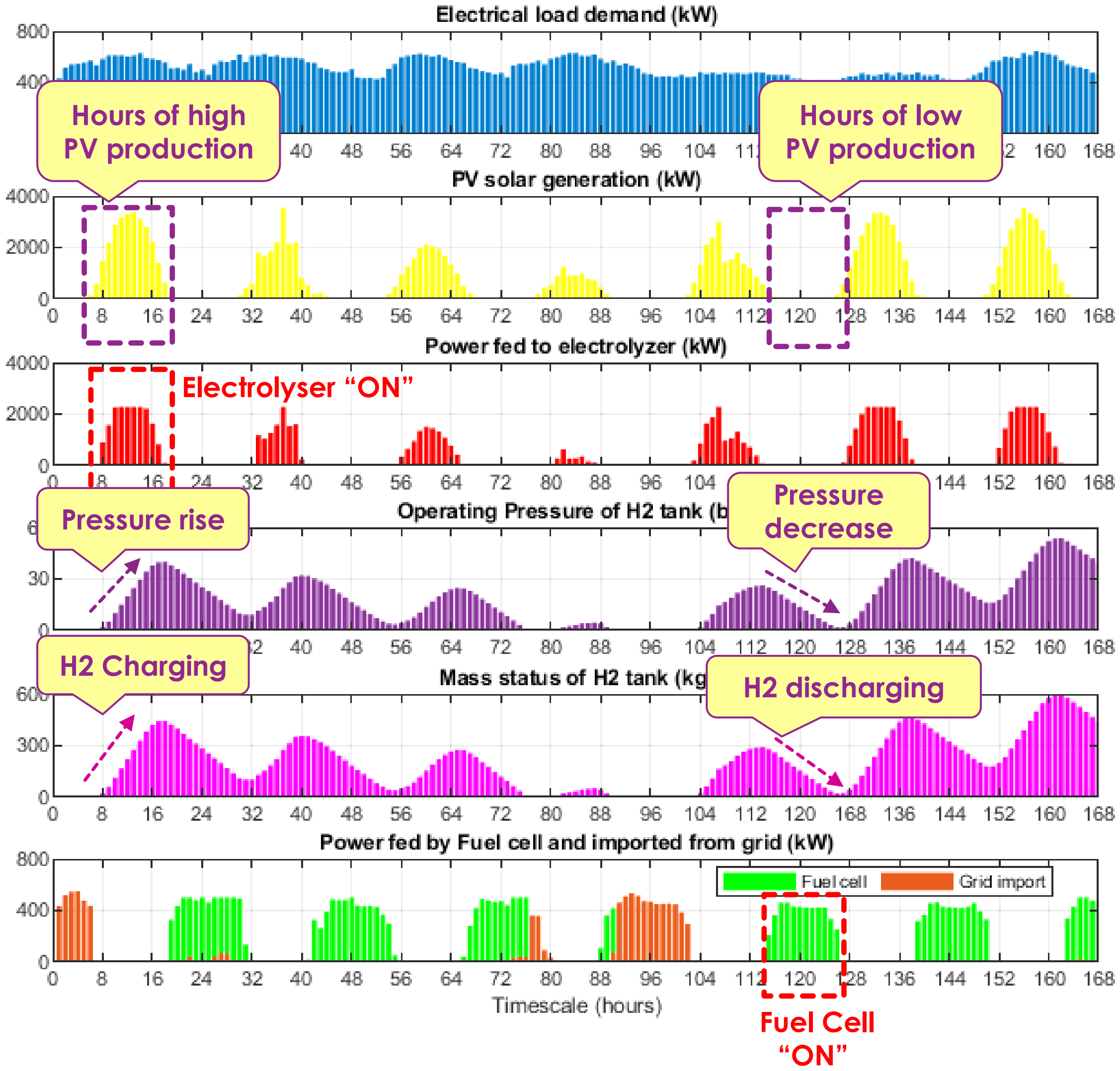
ROBERT GORDON UNIVERSITY ABERDEEN

Simulation Results of Hybrid PV-H2 Energy System

Simulation Results over one-year timescale

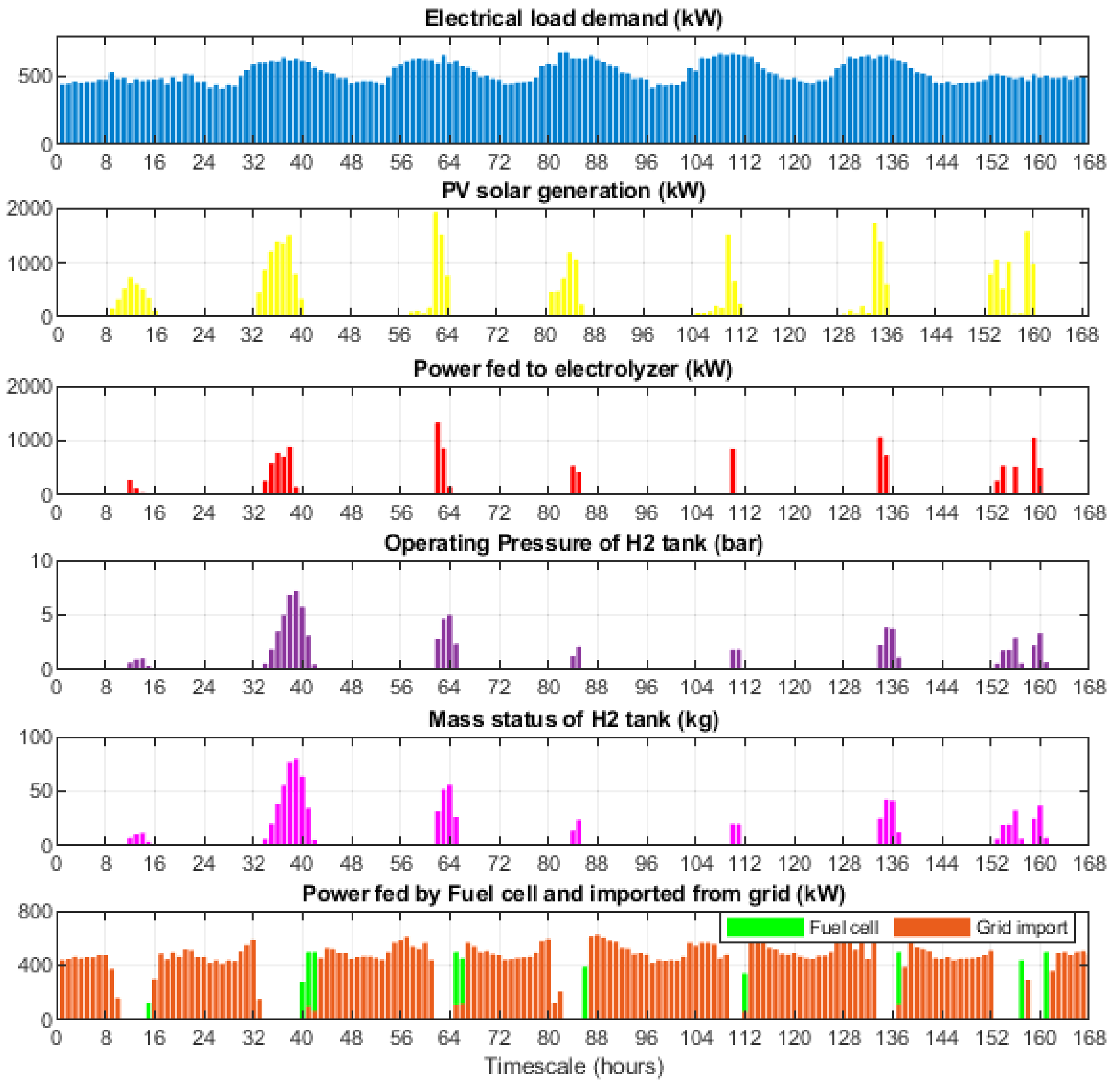


Simulation Results over one Summer week

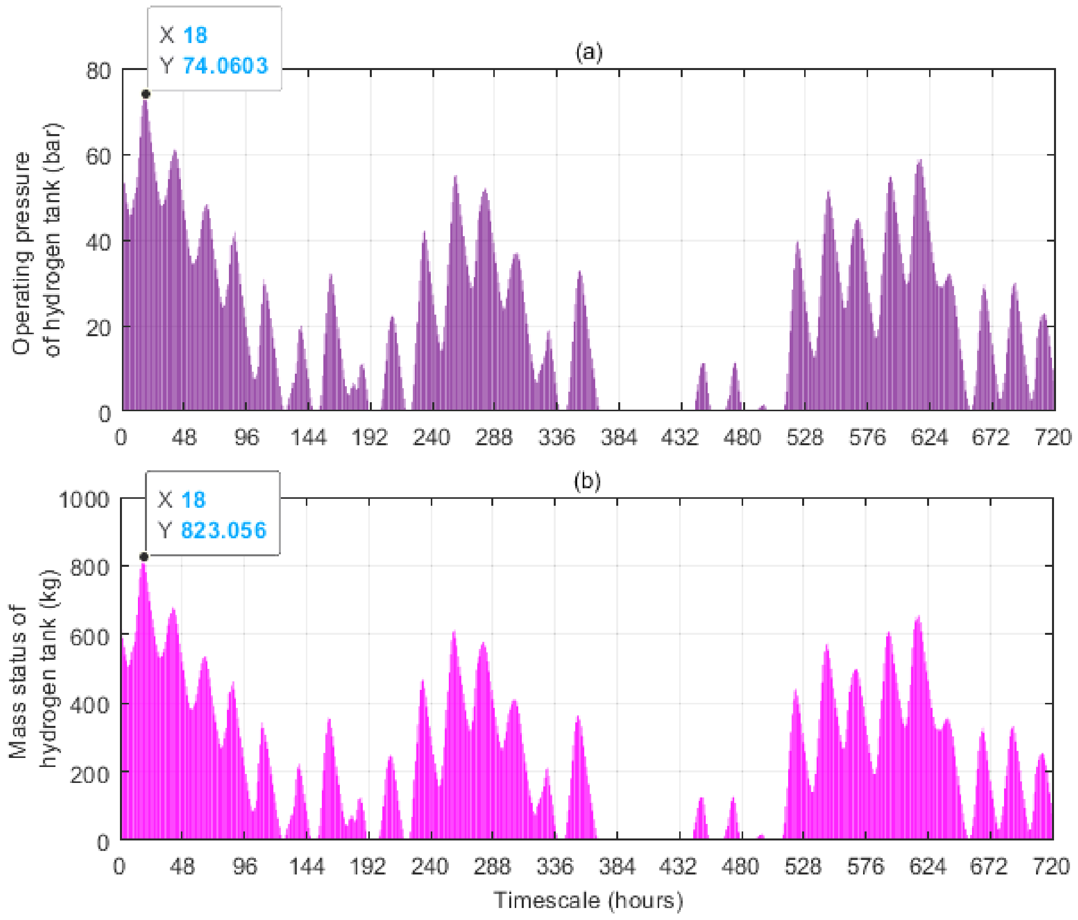


Simulation Results of Hybrid PV-H2 Energy System

Simulation Results over one Winter week

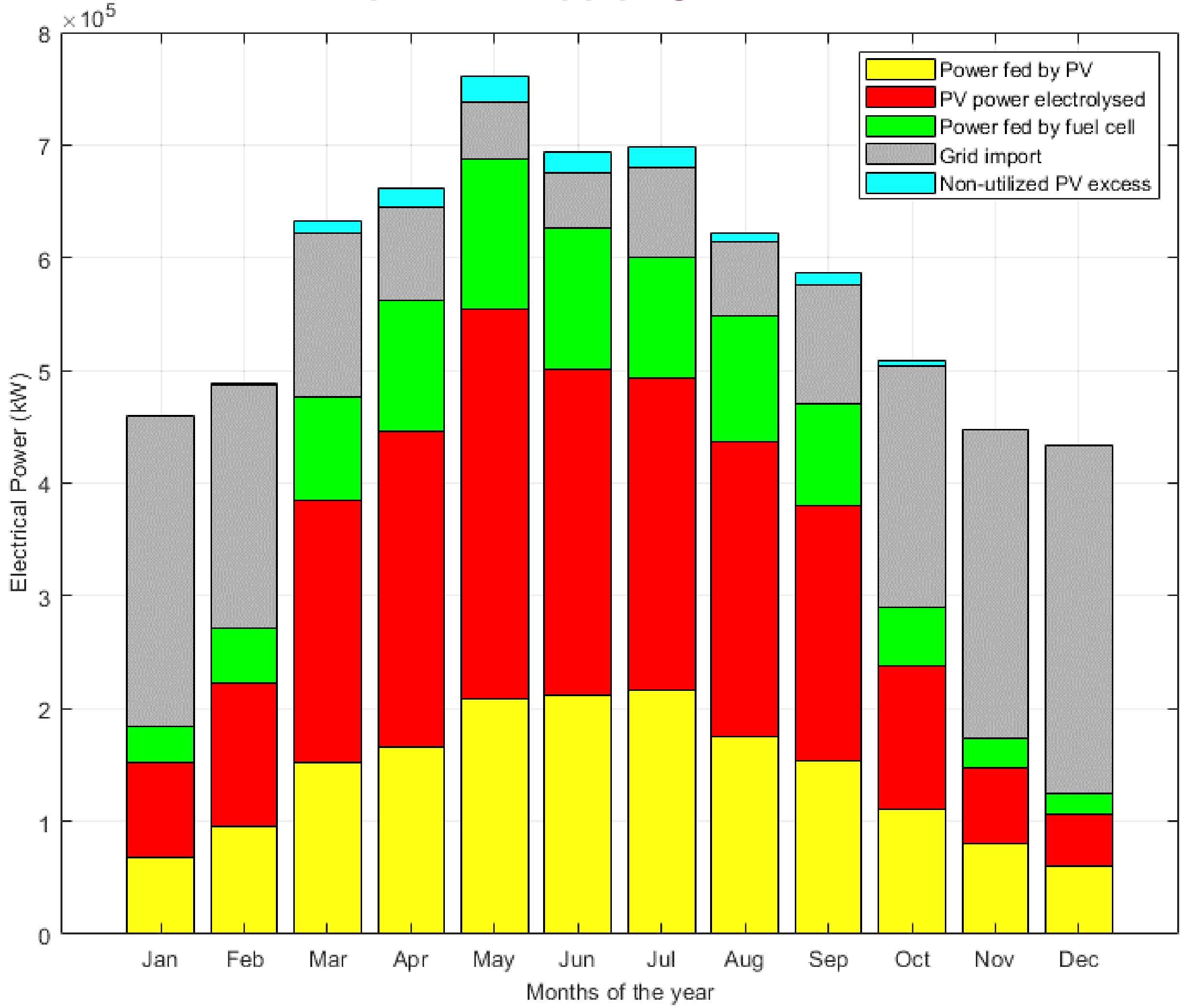


Simulation of Hourly status of H2 tank and the associated operating pressure during the month of June

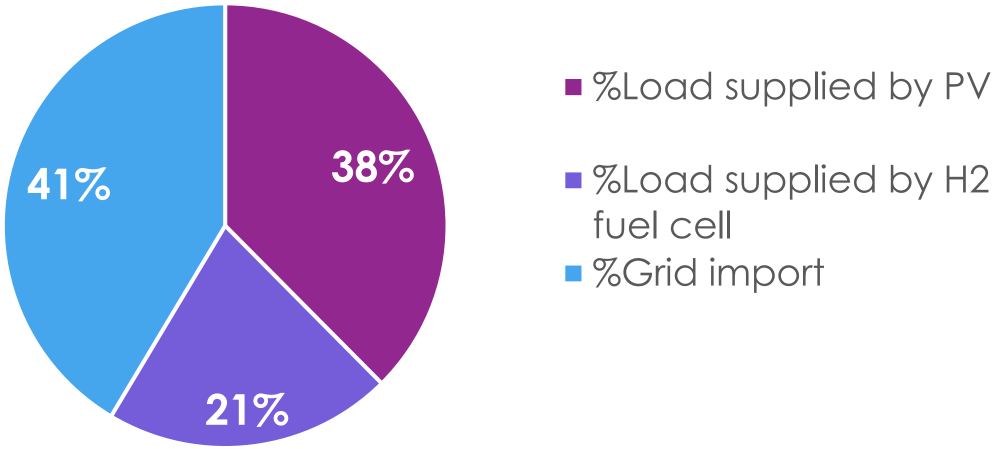


Simulation Results of Hybrid PV-H2 Energy System

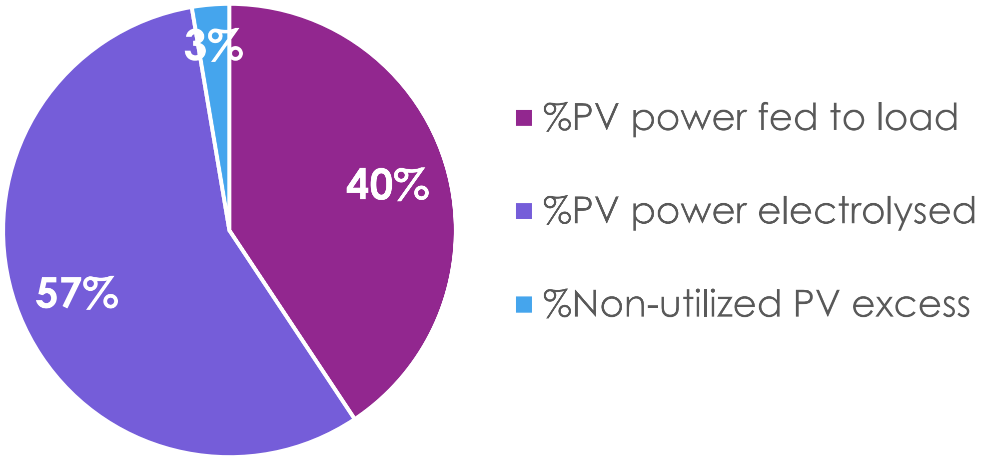
Monthly power exchange of the proposed Grid-connected PV-H2 System in supplying the load demands



Annual Contribution of the proposed grid-connected PV-H2 System in feeding load demands



Annual utilization of the proposed PV system capacity



ROBERT GORDON UNIVERSITY ABERDEEN

Conclusion

- A Capacity sizing and Energy Management Modelling has been developed for the proposed hybrid Photovoltaic-Hydrogen Energy System for grid-connected building scenario to support the building sector decarbonization while ensuring a reliable system operation

- The results have shown a maintained energy balance between the renewable generation, load consumption, green hydrogen production by electrolyser and consumption by fuel cell, with less contribution from the utility grid throughout the year.

- The integration of the proposed Hydrogen Energy Storage System has increased the total contribution of green energy in feeding the building load demand by 21%, while improving the utilization of the proposed PV system capacity by 59%.

Thank you!

Any Questions?