Investing in generation and coupling vector storage in a liberalised energy market: A game-theory based approach

Akhil Joseph, Adib Allahham, Sara Walker

Background

- Energy system of Great Britain (GB) is moving towards achieving a net zero-carbon emission target by 2050 [1].
- Various decision factors such as generation technologies, energy conversion technologies, energy market structure, and regulations play a crucial role to achieve such targets in an integrated liberalized energy market (Fig 1).
- In this work, we aim to investigate long-term investments in the liberalized energy market based on the short-term operability of the system.
- Study will focus on analyzing the impact of investments in renewable generation, hydrogen, and vector coupling storages. (To maximize social welfare and to minimize CO_2 emissions)
- A game-theoretic liberalized energy market framework is proposed.
  - Development of a game-theoretic model to simulate the annual investment model for generation and storage technologies.
  - Hourly operation of the model is simulated to capture the value of hydrogen, coupling components, and vector coupling storage (VCS).

Research Objectives

1. To demonstrate a game-theoretic model of the GB's integrated energy networks that simulates both the long-term investment and short-term operation of the energy sector.
2. To simulate how the GB's energy sector will evolve until 2050 with/without investing in various configurations of storage (hydrogen storage and vector coupling storage).
3. To simulate the investment behaviour into large-scale vector coupling storage and quantify its benefits.

Model structure

The model structure represents the interaction between the annual investment and hourly operational simulations (Fig 2).

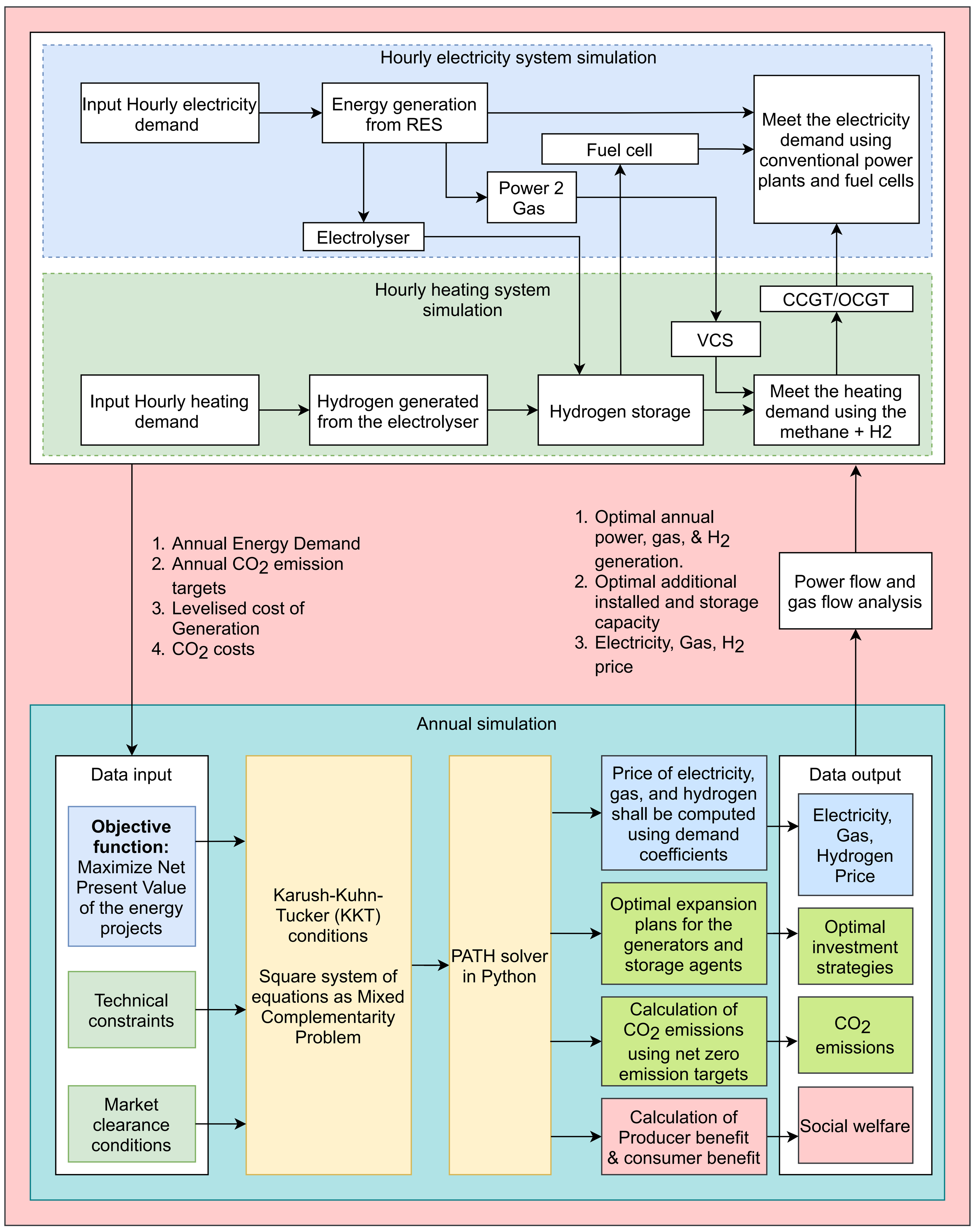

Fig 2: The model structure adopted for the simulation.

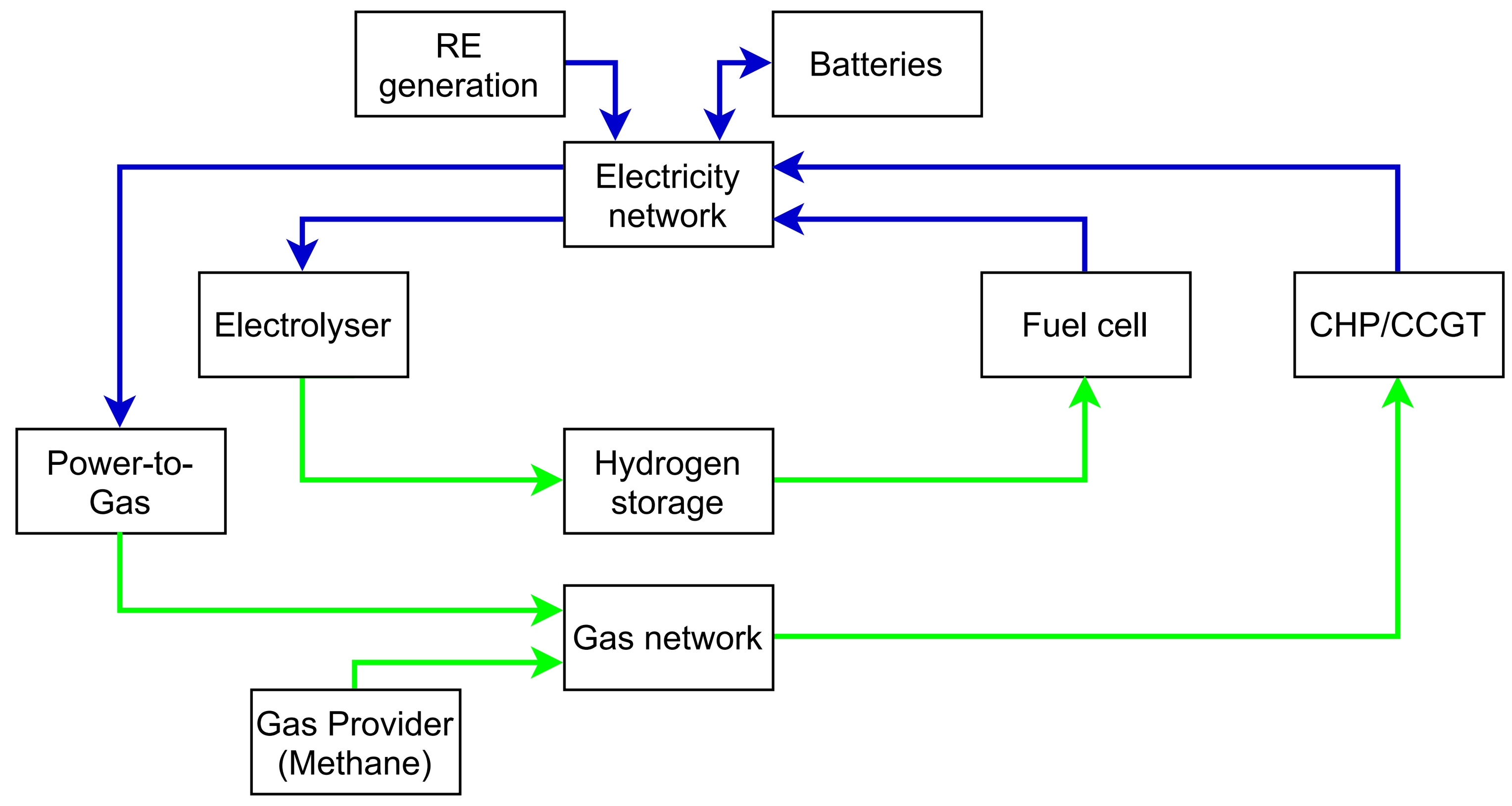

Fig 1: The interaction between the generators, single vector storage and vector coupling storage. (CHP: Combined Heat and Power, CCGT: Combined Cycle Gas Turbine)

Cournot Oligopoly Model

- Generators can potentially invest in additional generation capacities and vector coupling storage investors can invest in additional storage capacities for better profits.
- Simultaneous decisions are taken by the power generators for optimal power dispatch and capacity expansion. Whereas, storage investors decide on their dispatch cycle and storage capacity expansion to maximize their profits.
- Objective function for the given planning year is defined as:

$$NPV = AF\left[\sum_{t\epsilon T}(R_t - C_t - CO_t) - FC\right] - NI$$

(NPV: Net Present Value, AF: Annuity factor, R: Operational revenue, C: Operational cost, CO: Emission cost, FC: Fixed cost, NI: Net investment outlay)

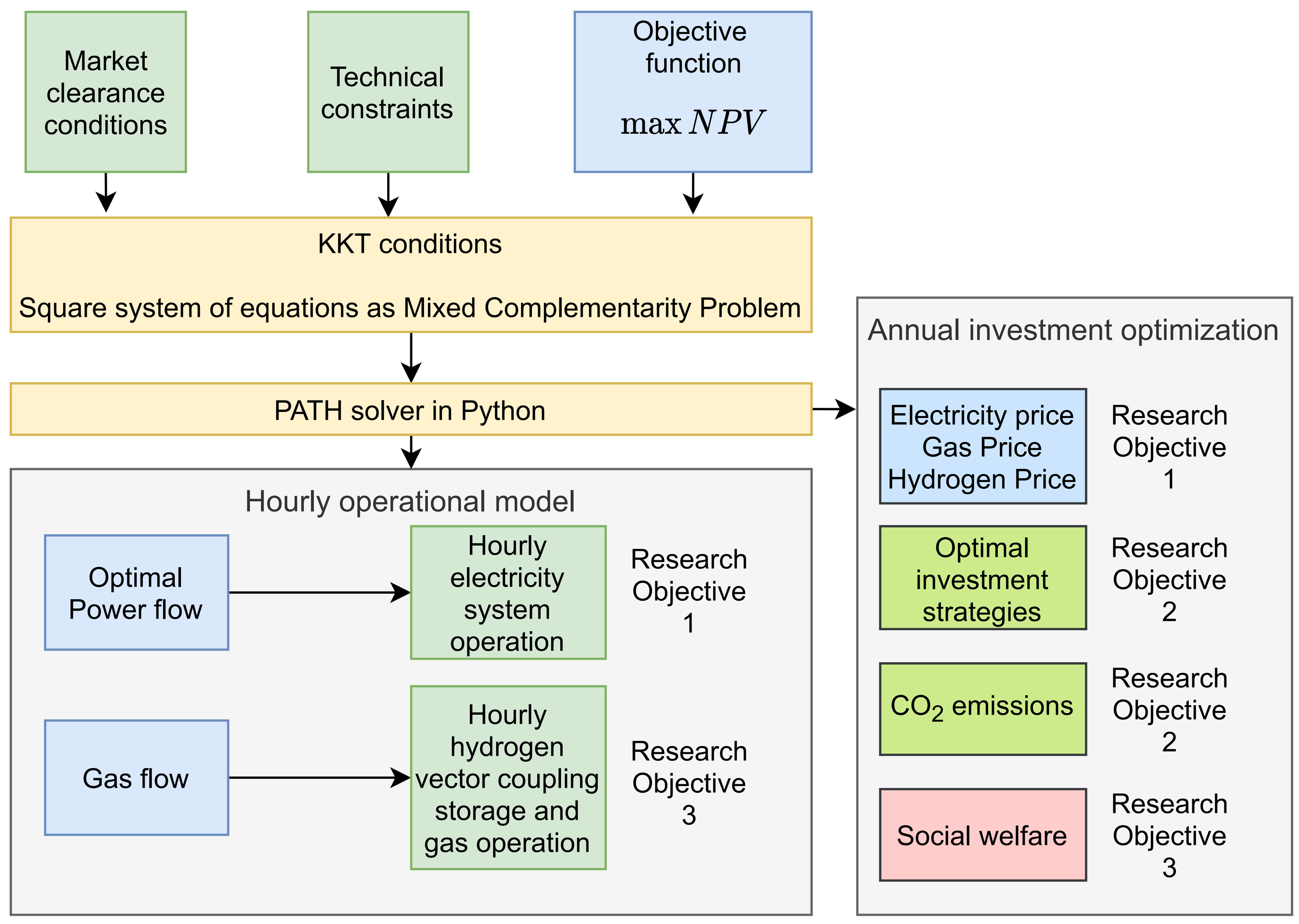

Fig 3: Formulation of objective function and constraints for the solver to obtain the results.

Discussion and Conclusion

- The simulation produces annual investment decisions and optimal generation quantities by the generators based on the forecasted load profiles.
- The annual optimal operational electricity, gas, and hydrogen production and storage strategies are converted to hourly operational model using power flow and gas flow models.
- Representative load curve data is used to reduce the computational complexity.
- The investment and generation strategies satisfy GB's net zero-carbon emission strategy by 2050

Reference

[1] HM Government, "Net Zero Strategy: Build Back Greener", OGL, October 2021 (Accessed on: 05 April 2022)