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Article

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Natural gas to improve energy security in Small Island Developing States: A techno-economic analysis



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ABSTRACT

There is a paucity of studies on natural gas-based energy production in Small Island Developing States (SIDS) even though technological improvements today are likely to make the application of natural gas more and more feasible. The development of natural gas in some of the regions of the Pacific, Africa, Indian Ocean and Caribbean attracts nearby countries and the coming up of the compressed natural gas (CNG) technology which can serve regional markets are two motivations for SIDS to develop natural gas-based energy provision. A third factor concerns long-term energy security. Due to continued reliance on fossil fuels and slow uptake of renewable energy, there is a need to diversify SIDS' energy mix for a sustainable electricity industry. Comparing the opportunities and constraints of liquefied natural gas (LNG) and compressed natural gas (CNG) in a SIDS-specific context, this paper discusses how to improve the integration of natural gas in prevailing energy regimes in SIDS as an alternative fuel to oil and complementary to renewable energy sources. To illustrate feasibility in practice, a techno-economic analysis is carried out using the island of Mauritius as an example.

1. Introduction

Energy development in Small Island Developing States (SIDS) have been understudied within the scientific literature (Shirley and Kammen, 2013). The energy situation in SIDS member states is characterised by high dependence on oil for electricity production and for transportation (Wolf et al., 2016). In the reckoning of the recent works of Kuang et al. (2016) and Timilsina and Shah (2016), it was reported that renewable energy resources have been scarcely developed in SIDS member states and there are still some barriers and challenges to be addressed to deploy more renewable energy. Yaqoot et al. (2016) categorised these difficulties in different sub-barriers such as technical, economic, institutional, socio-cultural and environmental barriers. In a review, Kuang et al. (2016) concluded that the randomness and variability of weather-dependent renewables, especially wind and solar, remains a major impediment for renewable energy diffusion in islands. In some SIDS member states like Haiti, Comoros, Guinea-Bissau and some countries in the Pacific, there is also a lack of reliable and affordable electricity (IEA, 2016; Dornan, 2014). No doubt that renewable energy can improve electricity access and diversify the electricity mix in SIDS member states, but following present barriers for more renewable energy diffusion – especially the inability to supply base load power that some renewable energy

resources cannot adhere to and the lack of some conducive energy policies to initiate continuous investment in the renewable energy sector – there is a need to investigate the impact of other energy sources within SIDS context.

This article proposes to integrate natural gas – the “cleanest fossil fuel” (IGU, 2016) as a reliable alternative to oil and, complementary to renewable energy sources within SIDS energy mix. During combustion natural gas produces less carbon dioxide than other fossil fuels, is not toxic and produces very little undesired ash and soot. The versatility, price and performance properties of natural gas make it a predominant fuel to collaborate with renewable energy like wind and solar and thus can limit energy vulnerability, increasing the level of energy security that SIDS face towards high oil consumption (IGU, 2015). Thermal power plants fuelled by natural gas is the ideal backup plan for renewable energy in SIDS member states. Some SIDS member countries have developed natural gas (Singapore, Papua New Guinea and Trinidad and Tobago) but in the remaining member states, this option has so far vaguely been investigated. This article also advocates for exploring the use of natural gas in SIDS as an alternative fuel to increase energy security and to achieve a better diversification of SIDS energy mix. It presents a technical analysis and the economic sustainability of natural gas projects for electricity generation for a randomly selected SIDS member state – Mauritius as example. The techno-

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economic analysis is based on a 25 MW capacity new natural gas plant taken as a baseline for calculation. For context, three key dimensions – transport, supply and distribution and potential uses are further elaborated.

2. Natural gas: prospects for SIDS

There is comprehensive literature depicting attributes and properties of natural gas use as a fuel source (Dobrota et al., 2013; Mazyan et al., 2016). From a technical point of view, it is easy to transport natural gas through pipelines, small storage units and gas cylinders. Since most of SIDS do not have any fossil fuel reserves, it is imperative for these island communities to import natural gas from supplier countries. Natural gas can be transported by sea in liquid form as Liquefied Natural Gas (LNG) or in gaseous form as Compressed Natural Gas (CNG) (commonly called marine CNG). Pipelining is also a feasible option to transport the gas but it is restricted to a very small distance undersea, making shipping the most viable means of transport.

Therefore, at first, it is imperative to determine the best transport option for transporting the gas from suppliers to exporters. Secondly, setting up a power plant working on gas requires the selection of the best technology suitable for SIDS. This is the aim of the thermo-economic analysis of suitable technologies that offers the best combination of efficiency and economics.

2.1. Transportation and storage choices

Liquefied Natural Gas (LNG) is the most practical means to transport natural gas over long distances. LNG has gained widespread attention in the world with 71 existing and 26 planned liquefaction plants in the world. Qatar remains the largest LNG exporter with 77 million tons per annum (MTPA) of natural gas produced (Mazyan et al., 2016). LNG requires specially designed carriers which can transport over 216,000 m³ of LNG (Dobrota et al., 2013). Stålhane et al. (2012) suggested that a 145,000 m³ capacity LNG carrier roughly costs US\$ 200–250 million to build with a daily charter rate as much as US\$ 80,000 which means that investment in LNG systems has huge financial implications and can considerably influence SIDS countries' budget allocation. A regasification facility is necessary to convert the LNG into natural gas form whose cost implications are almost ten times higher than a CNG decompression facility (Young and Eng, 2007). On the other hand, CNG is another method for transporting natural gas from wellheads to consumers in high-pressure steel containers. The process involves compressing the gas through a number of compression stages to a pressure of 20–24 MPa and intercooling it after each compression stage due to temperature rise from gas compression (Mazyan et al., 2016; Wang and Economides, 2009). The main advantages to CNG technologies are scalability, simplified production process, flexibility and affordability (Beronich et al., 2009; Nwoaha and Iyoke, 2013). CNG occupies a volume of less than 1% than it normally occupies at standard atmospheric pressure but, it requires a storage volume twice as much as that required for LNG storage (McGill et al., 2013). CNG can be transported in specialised CNG carriers or compressed in long tubes and stacked into a standard container ship (Kryzhanivskyy et al., 2013) but it is limited to a travel distance on 2500 km (Mallory, 2014) and its capacity is far lower than can be transported as LNG. Low amount of natural gas that can be transported in compressed gaseous form matches the low energy demand of SIDS. The large volume of natural gas that can be transported in liquid form makes it difficult for LNG to serve smaller markets commercially as the continuous running of large capacity of LNG carriers maintain high thermodynamic efficiency and low costs (Thomas and Dawe, 2003).

2.2. Possible natural gas supplier and distribution options for SIDS

Whereas LNG can cost-efficiently be distributed on a global level as large LNG carriers can supply natural gas over long distances from Qatar to Korea or from Norway to Maryland, pipelines are an effective national and international solution for short distance transport of gas over accessible terrain. Therefore, considering limitation over travel distance, it is generally acceptable that CNG can be used for regional transport rather than global transport making it intuitively suitable for application in SIDS (Young and Eng, 2007). With the discovery of gas fields in Mozambique and Tanzania, African SIDS (Mauritius, Seychelles) can potentially be supplied with natural gas; Australia and Papua New Guinea are possible gas suppliers in the Pacific SIDS and Colombia, Trinidad and Tobago and the United States can indeed export CNG to the Caribbean SIDS (Jamaica, Haiti, Dominican Republic and others). Of course, there are other aspects such as costs, geopolitical stability or reservoir characteristics to look for while considering market selection for gas procurement, but the gas suppliers mentioned hitherto, and with the development of CNG technology, can potentially place SIDS into a strategic position to invest in natural gas.

Another consideration that makes CNG transport economically attractive is the optimisation in size and itinerary of the CNG fleet. Two types of itinerary were discussed in Nikolaou (2010): 'hub-and-spoke' system and a 'milk-run'. For bigger markets, larger CNG vessels are more suitable and a hub-and-spoke trading pattern is preferable. The hub can be a gas production site or a regasification terminal where LNG is delivered and converted to CNG. For smaller markets where dedicated vessels cannot be justified, a milk-run configuration is more appropriate whereby vessels deliver CNG to multiple sites and download volumes to storage facilities to store gas until the next vessel visit. There, milk-run pattern makes it possible to deliver gas to small markets such as island communities which have aroused the interest of SIDS in natural gas. Grenada, Barbados, St Lucia, Bermuda, Bahamas and Haiti can be supplied by milk-run pattern and bigger islands communities like Jamaica and Dominica Republic can be supplied by a hub-and-spoke system.

2.3. Potential uses of natural gas in SIDS

CNG is widely used as an automobile fuel in countries like Iran, Argentina, Italy, Brazil and United States in buses, trucks and light duty vehicles and is the perfect candidate for replacing diesel and petrol (Benvenuti, 2010). CNG offers numerous benefits for bi-fuel engines (running on petrol or CNG at a time) or dual-fuel engines (engines modified to work on both diesel and CNG) (Lee, 2011). CNG is safer than petrol, diesel or even LPG as automobile fuel in the following ways:

- it is lighter than air and dissipates into the atmosphere in case of any leakage,
- it has a self-ignition temperature of 540 °C as compared to 450 °C for LPG, 220 °C for unleaded gasoline and 225 °C for diesel;
- storage tanks of CNG are constructed with special materials than can withstand high pressures and are far safer than petrol tanks (Amrouche et al., 2012; Bhattacharjee et al., 2010).

Another difference here that highlights the feasibility of CNG over LNG in SIDS is as automobile fuel. LNG also can be used as an automobile fuel but it is suitable for heavy haul transport. LNG is stored in thermally insulated tanks on-board vehicles and when the engine is started, the LNG is heated converting it back into gaseous form. LNG-fuelled heavy vehicles can pose a risk when unmoved for a week or more. These vehicles will vent out a flammable gas (generally BOG) that can explode upon contact with an ignition source. Therefore to address this issue, LNG is restricted to frequently-driven fleet and serviced by trained personnel (Howell and Harger, 2013).

3. Power generation in SIDS: Case study of Mauritius

In this section, Mauritius is taken as case study to illustrate the feasibility of setting up a natural gas project in an island context. Mauritius is a small island of 2040 km² located in the east of Madagascar in the Indian Ocean (Surroop and Raghoo, 2017). CNG thus is the most feasible option from an economic, social, environmental and technical perspective. The aim is to study the potential use of CNG within the Mauritian energy sector for a 25 MW gas power plant. Several 25 MW plants can be replicated in case of higher capacity in other SIDS. The supplier country considered is Mozambique in this case (Demierre et al., 2015). In the case of Pacific region, Papua New Guinea and Australia can be the supplier and in the case of Caribbean, Trinidad and Tobago, USA and Colombia can be the supplier. Four different technologies were considered using CNG as fuel which are a simple gas turbine, a natural gas combined cycle (NGCC), a Cheng cycle and gas engines. The ultimate aim is to give potential investors an insight of each technology for better decision making on a power plant project and to trigger investment opportunities in small island communities with no natural gas reserves.

3.1. Assessment methods

3.1.1. Methodology for technical evaluation

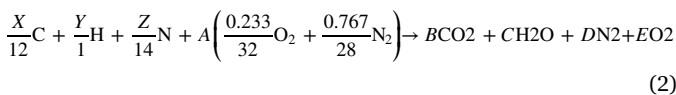
There is a wide range of papers and textbooks depicting the working principle (Giampaolo, 2006; Kaushik et al., 2011; Kehlhofer et al., 1999; Kostyuk and Frolov, 1988; Peltier, 2006; Pinelli and Bucci, 2009; Poullikas, 2005; Snow, 2002; Wadhah and Al-Doori, 2011) of the selected technologies and no attempt was made to repeat same in this article. Technical evaluation of selected technologies was conducted by accessing relevant formulae and calculation procedures from engineering textbooks and scientific publications. Without oversimplifying the calculation procedures, combustion losses and pressure drops were assumed negligible and turbine and compressor efficiencies were adiabatic. Hand-held and paper based calculations were used (rather than simulation software) as it will help engineers, policy makers and decision makers to replicate same methodology in their island context more easily. Table 1 gives the composition of the natural gas for the study.

The energy content that is, Lower Heating Value (LHV) of natural gas was calculated from Eq. (1) (Eswara et al., 2013).

$$\text{LHV of natural gas} = \frac{\sum(x_i \cdot MW_i \cdot HHV_i)}{\sum(x_i \cdot MW_i)} - Q_{H_2O} \times [(M_{H_2O}/M_{H_2})H + F] \quad (1)$$

where MW_i is the molecular weight of component i , HHV_i is the Higher Heating Value of component i , Q_{H_2O} is latent heat of vaporisation of water at normal conditions (2.256 MJ/kg), M is the molar mass and H and F are the weight percentages of hydrogen and moisture respectively.

The mass of air required for combustion were obtained by elemental balances. It was assumed that air contained 23.3% oxygen and 76.7% nitrogen by mass (Rathore, 2010).



The stoichiometric amount of air, f is given by

$$f = \frac{32}{0.233} \times \left[\frac{X}{12} + \frac{Y}{4} \right] \quad (3)$$

and the actual amount of air required, m_{air} in kg/kg fuel = $f \times AFR$ (4)

where X , Y and Z are the weight percentages of carbon, hydrogen and nitrogen respectively and AFR is the excess air to fuel ratio. The AFR in the combustor was 250% in accordance with Ganesan (2010) and Martinez et al. (2011). It should be noted that a large volume of air is

Table 1

Natural gas composition in mole percent^a.

Constituents	Methane	Ethane	Propane	Butane	Nitrogen
Composition	86.98	9.35	2.33	0.63	0.71

^a The composition was obtained from Madagascar and varies from wellheads.

used in a gas turbine as besides the combustion process, the air is used to protect the combustor from high thermal stresses on the turbine structure (Martinez et al., 2011).

For a **simple gas turbine** (Fig. 1), the ambient air temperature (T_1) drawn by the compressor is at 25 °C. Assuming ideal gas behaviour and a compressor efficiency of 0.87 (Saravanamuttoo et al., 2001), the high temperature air leaving the compressor can be evaluated by (Oyedepo and Kilanko, 2014)

$$T_2 - T_1 = \frac{T_1}{\eta_{sc}} \left[\left(\frac{P_2}{P_1} \right)^{\frac{k_c - 1}{k_c}} - 1 \right] \quad (5)$$

where η_{sc} is the isentropic efficiency of the compressor, p_2/p_1 is the compressor ratio, assumed 14, and k_c is the ratio of specific heats of air in the compressor, taken as 1.40 (Cengel and Boles, 2006).

The power consumed by the compressor, P_c is given by (Jeetah, 2014)

$$\text{Compressor power, } P_c = m_{air}(h_{2,air} - h_{1,air}) \quad (6)$$

where $h_{2,air}$ and $h_{1,air}$ are the enthalpies of air at T_2 and T_1 respectively.

The temperature drop that occurred in the gas turbine was evaluated from (Naradasu et al., 2007; Rahman et al., 2011):

$$T_3 - T_4 = T_3 \eta_{ST} \left[1 - \frac{1}{\left(\frac{P_3}{P_4} \right)^{\frac{k_T - 1}{k_T}}} \right] \quad (7)$$

where the outlet turbine temperature T_4 , is 543 °C,¹ the isentropic efficiency of the turbine, η_{ST} is assumed as 0.90 (Kumar et al., 2010), the ratio p_3/p_4 equals to p_1/p_2 as no combustion losses were assumed and k_T for the gas turbine is taken as 1.181 (Cengel and Boles, 2006).

The turbine gross power output is equal to

$$P_T = m_{gas}(h_{3,gas} - h_{4,gas}) \quad (8)$$

where $h_{3,gas}$ and $h_{4,gas}$ are the enthalpies of flue gas at inlet and outlet of the gas turbine respectively and m_{gas} is the mass flow rate of flue gas and it is given by

$$m_{gas} = m_{air} + m_{fuel} \quad (9)$$

or more specifically by,

$$m_{gas} = m_{air}(1 + \beta) \quad (10)$$

where β is the specific fuel consumption given by Eq. (11). Energy balances and derivation of Eq. (11) is found in Jeetah (2014).

$$\beta = \frac{h_{3,air} - h_{2,air}}{LHV - h_{3,air} - (1 + f)DH_3} \quad (11)$$

where DH_3 is the enthalpy difference between combustion gas and air at T_3 .

The net power delivered by the gas turbine was computed from

$$P_{net} = \eta_G(P_T \eta_m - P_c) \quad (12)$$

where η_G is the generator efficiency and η_m is the mechanical efficiency

¹ Data from manufacturer (Siemens AG); achieved at a turbine speed of 7700rpm and a frequency of 50/60Hz.

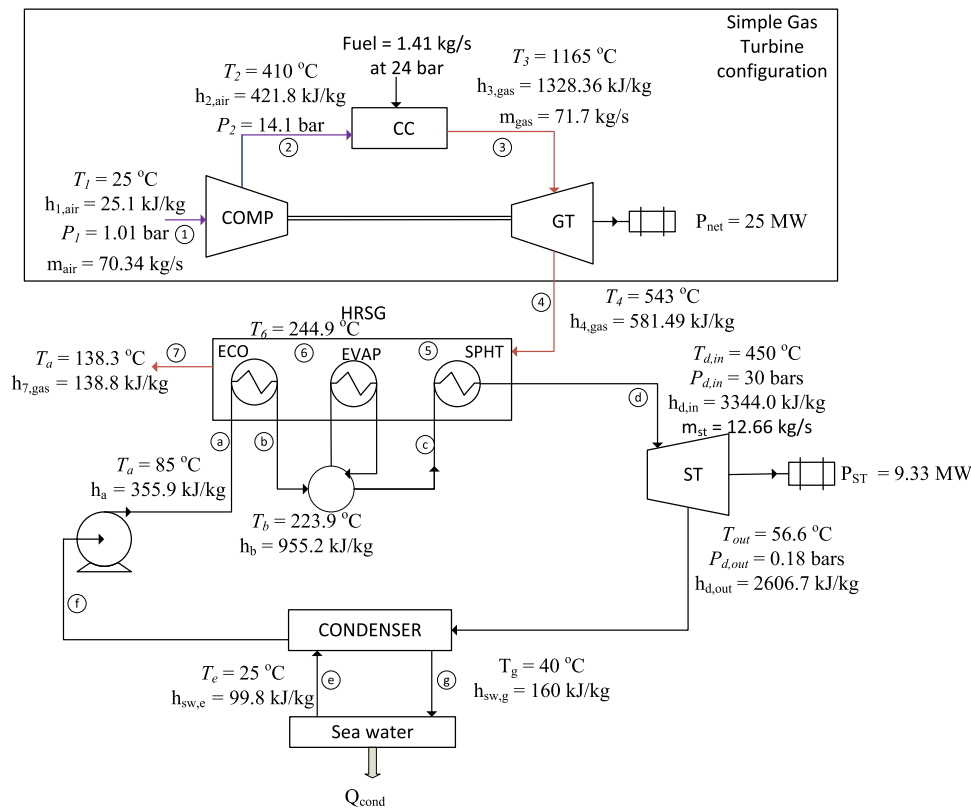


Fig. 1. Schematic of from the technical analysis of the NGCC plant.

both taken as 98% (Kumar et al., 2010; Saravanamuttoo et al., 2001).

Power produced per kg fuel burnt (kW h/kg) is evaluated from

$$\text{kW h per kg CNG} = \frac{P_{net}}{\beta \cdot m_{air} \times 3600} \quad (13)$$

where $\beta \cdot m_{air}$ represents the mass of fuel burnt

The electrical efficiency can be determined from (14) as:

$$\text{Electrical efficiency} = \frac{P_{net}}{\beta \cdot m_{air} \cdot LHV} \times 100\% \quad (14)$$

The natural gas combined cycle (NGCC technology) (illustrated in Fig. 1 itself) is an extension of a simple gas turbine technology to ultimately provide a more efficient power generation system. A NGCC is a combination of two cycles in a single power plant. The waste heat in the flue gas exiting the first cycle (known as the topping cycle) is used to generate superheated steam in a Heat Recovery Steam Generator (HRSG). The steam is then injected in a steam turbine which activates a generator and produces electricity. The amount of steam generated, assumed at 30 bars and 450 °C, was given by Eq. (15) (Ganapathy, 1994).

$$\text{Steam generated, } m_{st} = \frac{m_{gas} \times (h_{4,gas} - h_{6,gas}) \times \eta_{evap}}{(h_{st,sat} - h_b) + BD(h_w - h_b)} \quad (15)$$

where m_{gas} is the mass of flue gas, h_{gas} is the enthalpy of flue gas at the corresponding streams, BD is the blowdown percent, $h_{st,sat}$ is the enthalpy of saturated steam at 30 bars, h_w is the enthalpy of saturated liquid at 30 bars and h_b is the enthalpy of feedwater entering evaporator at T_b .

Temperature of feedwater entering the evaporator is calculated by

$$T_b = T_{sat} - T_{app} \quad (16)$$

where T_{sat} is the saturated liquid temperature at 30 bars and T_{app} is the approach temperature in the HRSG.

The power that can be generated in the steam turbine is given by Eq. (17). Steam entering the steam turbine is at superheated conditions

and the fluid exits under vacuum at saturated conditions at a pressure of 0.186 bars (Swanekamp et al., 1998).

$$\text{Power generated by steam turbine} = m_{st} \times (h_{d,in} - h_{d,out}) \quad (17)$$

where $h_{d,in}$ is the enthalpy of superheated steam entering turbine and $h_{d,out}$ is the enthalpy of steam leaving the turbine.

The configuration of the Cheng cycle is illustrated in Fig. 2. An attribute of the Cheng cycle is that the steam generated from the HRSG is injected back to a flexible gas turbine, instead of feeding into a steam turbine. The main advantages of this configuration is (a) lower investment capital compared to the NGCC; (b) higher efficiency as compared to a simple gas turbine and (c) lesser NO_x formation as the steam injected reduces peaks in flame temperature.

The amount of steam to be injected in the gas turbine is limited to a certain amount as the steam will tend to decrease the adiabatic flame temperature in the combustor and hence, decrease the overall efficiency. The optimum amount of steam that can be generated and injected is derived from energy balance around the combustor and is simplified to Eq. (18) as:

$$m_{st} = m_{air} \frac{\beta [LHV - h_{3,air} - (1+f)DH_3] - h_{3,air} + h_{2,air}}{h_{3,st} - h_{d,st}} \quad (18)$$

where $h_{3,st}$ is the enthalpy of steam entering gas turbine and $h_{d,st}$ is the enthalpy of steam leaving the HRSG. Alternatively,

$$h_{3,st} - h_{d,st} = C_{p,av}(T_3 - T_d) \quad (19)$$

where $C_{p,av}$ is the average specific heat capacity of superheated steam and T_3 and T_d are the steam temperature at streams 3 and d respectively.

The total power generated from a Cheng Cycle is given as in Eq. (20). The steam in general does not to participate in any chemical reactions.

$$P_T = m_{air}(1 + \beta)(h_{3,gas} - h_{4,gas}) + m_{st} C_{p,av}(T_3 - T_d) \quad (20)$$

For the gas engines, Eqs. (21) and (22) can be used to determine the

SCENARIO 3: Steam Injection Gas Turbine System – Cheng Cycle

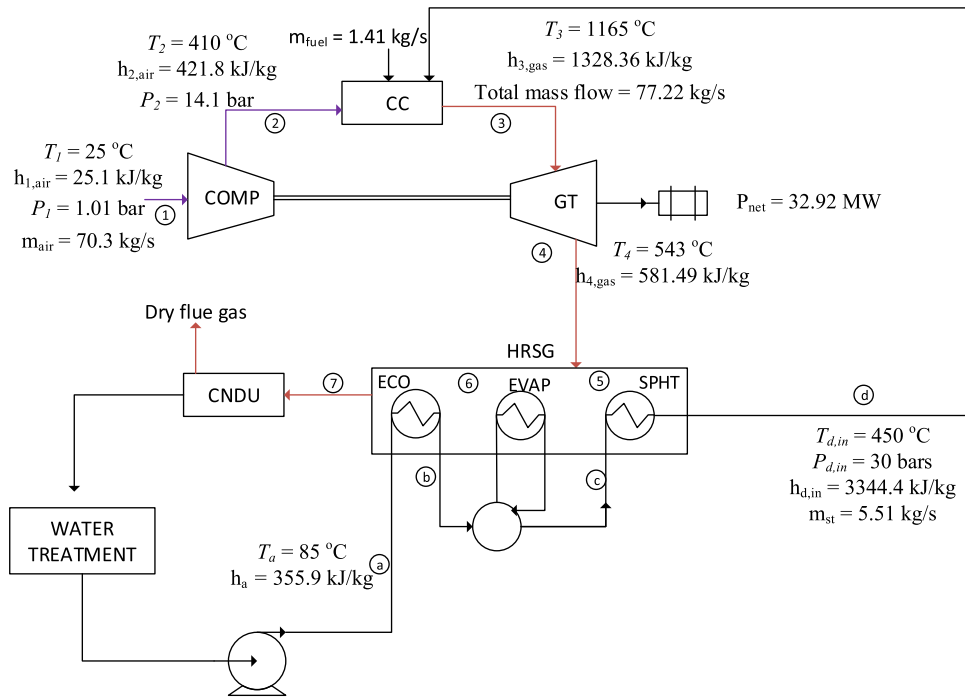


Fig. 2. Schematic of the Cheng cycle with complete energy balance.

kWh electricity per kg CNG. Jenbacher J624 gas engine was chosen for the study. The engine has an efficiency of 46.5%.

$$\text{Heat rate, kJ/kWh } h = \frac{1}{\text{Efficiency}} \times 3600 \quad (21)$$

$$\text{kWh produced per kg} = \frac{\text{Lower Heating Value}}{\text{Heat rate}} \quad (22)$$

A Jenbacher J624 produces a maximum of 4 MW power and to satisfy our 25 MW power plant at least 7 such engines are required. It is advisable to install seven small capacity engines rather than two high capacity engines as in case the plant has to go off-grid for schedules maintenance or unplanned repairs, the plant can still export the required power to the grid. In a power plant employing engines, the CNG flows through pipelines to a pressure stabilising tank where the pressure is adjusted for the engines. Gas turbines work with inlet fuel pressure of about 24 bars as compared to engines which are designed to receive fuel at 7 bars.

3.1.2. Methodology for economic evaluation

It is worth mentioning, that data unavailability (related to cost of equipment, insurance, taxes, depreciation) for the economic analysis of the natural gas project has constrained the choice of the methodology. The estimation to determine the economics of the project started by collecting quotes from manufacturers and suppliers. Based on these quotations, the Chemical Engineering Plant Cost Index methodology was applied for reliable cost estimates (Peters and Timmerhaus, 1991). Another limitation of the economic evaluation was the unavailability to obtain accurate transportation costs involved in the importation of the gas.

The cost of generated 1 kWh of electricity is estimated as in Kehlhofer et al. (1999) as:

$$Y_{EL} = \frac{TCI \cdot \psi}{P \cdot T_{eq}} + \frac{Y_F}{\eta} + \frac{U_{fix}}{P \cdot T_{eq}} + u_{var} \quad (23)$$

where TCI: Total Capital Investment cost in \$, P is the rated power output, MW; T_{eq} , equivalent utilization time at rated power output

(in h/a), Y_F , price of fuel (\$/MW h), η as plant efficiency, U_{fix} as fixed cost of operation, maintenance and administration (\$/a) and u_{var} as variable cost of operation, maintenance and repair (\$/MW h). The annuity factor, is calculated by

$$\psi = \frac{q-1}{1-q^{-n}}, 1/a \quad (24)$$

where, $q = 1 + z$; z is the discount rate (%/a) and n, the amortization period in years.

For calculation purposes, the discount rate is taken as 5.5% (Kehlhofer et al., 1999) and the amortization period was assumed as 25 years.

3.2. Results from technical analysis

Figs. 1 and 2 provide detailed analysis of each technology. The results for the thermodynamic analysis of the selected technology candidates are summarised in Table 2. It was seen that the simple GT cycle generates less power per kg CNG burnt, that is 4.93 kWh/kg, than other technologies selected for the study. As the system is optimised into a NGCC or Cheng Cycle, the power generated per kg CNG increases, as well as the overall power available to export to the grid and the overall efficiency of the process. A combined cycle technology gives the highest power out of 6.83 kWh/kg of fuel. Technically, the technology that provides the higher efficiency and higher power output is favoured but besides technical aspect, the economic aspect is also

Table 2
Technical Assessment.

Scenario	Power output (kWh/kg)	Energy exported (GWh/year)	Efficiency (%)
Simple GT cycle	4.93	200	36.8
Steam injection GT	6.45	261	48.1
Gas engines	6.23	222	46.5
Combined cycle	6.83	272	51.0

Table 3
Economic Analysis.

	Scenario 1: Gas Turbine	Scenario 2: NGCC	Scenario 3: Cheng Cycle	Scenario 4: Gas Engine
Total Capital Investment (US\$ million)	58.6	139.4	109.2	78.0
Total Product Cost (US\$ million)	15.7	32.8	26.6	19.9
Gross earnings (US\$ million/year)	5.4	5.8	5.7	2.9
Discounted payback period (year)	4.54	5.88	5.74	5.91
Investment Cost (US\$/kWh)	0.30	0.52	0.37	0.35
Cost of electricity (\$/kWh)	0.11	0.15	0.15	0.10

essential for the selection of the best option.

3.3. Economic analysis

The results of the economic analysis are given in Table 3. A simple GT technology provides the lowest capital investment in a natural gas power plant. Since the NGCC and the Cheng Cycle are extensions of the simple GT system, the capital investment required is higher and in the order of \$139 million and \$109 million respectively. The second most affordable option is gas engines which require an investment of about \$78 million. Interestingly, even though gas engines require relatively lower capital cost, accrued gross earnings is relatively lower for gas engines because electricity production cost from gas engines is lower and for this reason, gas engines encounter higher payback period.

4. Discussion and conclusion

The technical and economic aspects of natural gas power plant fuelled by CNG is analysed for the SIDS member states of Mauritius. A simple GT cycle produces the lowest power output that other technologies studied. Considering the relatively low investment cost that a gas turbine and engines offers, these two technologies can potentially be appropriate solutions for a power plant project in Mauritius. Later on, after achieving more expertise on the working of these technologies, the latter can be optimised and expanded into NGCC or the Cheng cycle. SIDS are basically countries which share similar economic environment even though these countries are different culturally and geographically. Hence, the application of CNG for power generation opens the debate for its potential application in other SIDS member states as supplier markets is nearby (Australia, USA, Columbia, Trinidad and Tobago, Mozambique among others).

As a remedial solution to decrease dependence on oil to decarbonise the energy sector and to combat climate change, natural gas is proposed as an alternative fuel source for SIDS in this article. Since SIDS have limited or no gas reserves, it is imperative for SIDS to resort towards natural gas imports, and a key issue to tackle is the transportation mode. Natural gas can be transported in either CNG or LNG. A literary comparison between both modes revealed that CNG is more practical in a SIDS context based on economics and logistics. In the case study, Mauritius was taken as a baseline scenario to show the techno-economic feasibility to CNG fuelled power systems in a SIDS. Additionally, such gas turbines and engines can with little effort be up-scaled in case higher capacity is required. Further research integrating the transportation dimension may be needed to complement technological feasibility studies to improve the explanatory value of such SIDS-related case studies. Finally, this research may serve to give policy makers insights into a set of technologies to support decision making regarding power plant investment planning for small island communities with no natural gas reserves.

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