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Sustainable energy from renewable biological resources: Sugarcane bagasse energy cogeneration in Mauritius

Introduction

A sustainable environment is a precondition for sustainable economic development. When an economy produces GDP by using energy and other inputs, the planet produces an invisible product, known as photosynthetic product of the planet (PPP) as a natural process. This PPP however contributes to the production of GDP as an invisible input. As GDP increases, there are adverse effects on the growth of PPP due to utilisation of environmental and natural resources. If degradation of the environment is not arrested and exhaustible natural resources are not conserved, the natural growth of PPP and consequently, future GDP growth will decline. In other words, the environmental cost of producing GDP will tend to increase, alongside the threats posed by global warming.

Energy is important for any economic activity in modern times. There are various sources of energy, which can be broadly classified as renewable and non-renewable. In recent years, greater emphasis is being placed on renewable sources of energy because they are sustainable as well as clean. UNDP (2000) defines sustainable energy as energy that is produced and used in ways that simultaneously support human development over the long term in all its social, economic and environmental dimensions. Sustainable energy not only refers to a continuing supply of energy, but to the production and use of energy resources in ways that promote – or at least are compatible with – long-term human well-being and ecological balance.

Negative environmental externalities in electric power markets contribute extensively to erosion of PPP. Acid rain, depletion of ozone, and climate change are attributed to the use of non-renewable resources, such as fossil fuel and coal in power generation. Renewable resources are considered to be critical to attaining the objective of environmental sustainability. There are important sources of renewable energy, namely wind, solar, ocean current, water and agricultural crops such as corn and sugarcane.

Sugarcane is a plant whose ancillary products and waste streams have a value such as: bagasse (cane trash) for energy, filter cake/furnace ash as soil conditioner, molasses for ethanol and spirits, and vinasse as fertiliser. Bagasse is the fibrous residue remaining after sugarcane or sorghum stalks are crushed to extract their juice. The use of sugarcane bagasse as an alternative energy source has assumed a special significance in sugarcane-producing countries. Sugarcane is a major commercial agricultural crop in the vast majority of African countries. As one of the plants with the highest bioconversion efficiency in terms of using solar energy for photosynthesis, the sugarcane plant is able to fix 55 tonnes of dry matter per hectare of land on an annually renewable basis. Under current practices, about half of this dry matter is harvested in the form of cane stalk for sugar recovery with the fibrous fraction, known as bagasse, combusted to fulfil the energy requirements of the sugar recovery process. A number of countries, in particular those without fossil fuels, have implemented bagasse-based energy production to minimise the use of co-generated energy from steam and electricity during sugarcane processing and to export excess electricity to the power grid of public power stations.

Box 17.1. Renewable v. non renewable energy

Sun, wind, water and geothermal energy have been around since the Earth was formed and are renewable (self-sustaining) energy sources. However, they can be difficult and often expensive to harness and large amounts are needed to produce only small amounts of electrical or fuel energy. The process of generating and using such energy sources is nevertheless more environmentally friendly.

Oil, natural gas and coal are economically efficient energy sources because with small amounts we can produce relatively large amounts of electrical or fuel energy. However, they are non-renewable energy sources, which once used up, can't be replaced and large-scale pollution may be created when oil and coal are used for energy.

The use of biomass (plants, corn and waste) energy has the potential to greatly reduce greenhouse gas emissions. Burning biomass releases about the same amount of carbon dioxide as burning fossil fuels. However, fossil fuels release carbon dioxide captured by photosynthesis millions of years ago – an essentially 'new' greenhouse gas. Biomass, on the other hand, releases carbon dioxide that is largely balanced by the carbon dioxide captured in its own growth (depending how much energy was used to grow, harvest, and process the fuel). So it is the net environmental benefits of biomass energy, and its renewable nature from local resources, which attract our attention. Moreover, developing new sources of environmentally friendly energy reduces dependence on fossil fuels and coal, which are not widely available in small islands.

Box 17.2. Definition of photosynthesis

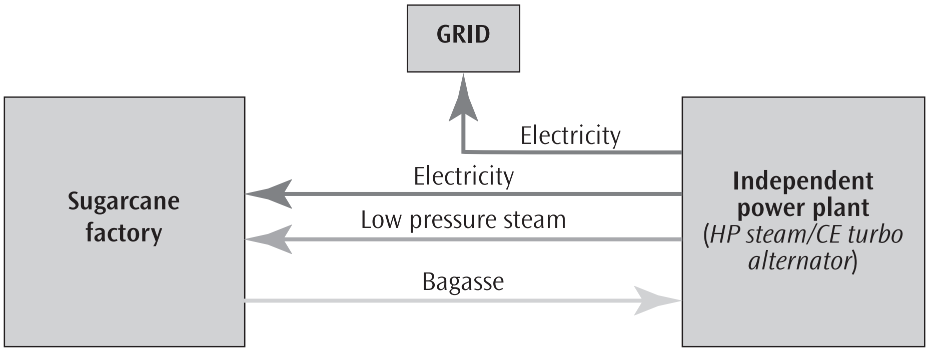
Photosynthesis is a series of enzyme-catalysed steps for the conversion of light energy into chemical energy by living organisms. Its initial substrates are carbon dioxide and water; the energy source is light (electromagnetic radiation); and the end-products are oxygen and (energy-containing) carbohydrates, such as sucrose, glucose or starch. This process is arguably the most important biochemical pathway, since nearly all life on Earth, either directly or indirectly, depends on it. It is a complex process occurring in higher plants, algae, and bacteria such as cyanobacteria.

The remainder of this chapter is set out as follows: The next section discusses the meaning and the process of cogeneration. The positive environmental impacts of cogeneration, use of bagasse and the underlying environmentally friendly technology are also analysed. A case study of cogeneration in Mauritius follows. The fourth section is devoted to an analysis of critical success factors and constraints underlying cogeneration. Next, an attempt is made to discuss the potential of bagasse-based renewable energy and sugarcane agriculture along with case studies. This section also discusses the prospects of developing sustainable energy islands. The last section offers some concluding remarks.

Cogeneration and positive environmental impacts

Cogeneration is the simultaneous production of electricity and steam (or heat) in a single power plant (see Figure 17.1). It represents a saving when compared to separate generation of electricity and steam (or heat). It is most commonly used in sugar mills where bagasse, a fibrous residue after cane crushing, is used as fuel. Sugar factories and individual power producers are required to utilise bagasse to generate low pressure heat as well as electricity. In the absence of cogeneration, bagasse will be used to generate heat and electricity will be purchased from public power stations. It is important to note that in the absence of an aggressive policy of cogeneration, sugar mills will fully utilise bagasse to meet their heat and part of their energy requirement. An appropriate cogeneration policy will not only make sugar mills independent in terms of their energy needs but they can also produce energy for use by other sectors, including households. Cogeneration is prevalent in Brazil, Thailand, India and many African countries, including Mauritius.

Figure 17.1. Typical sugar factory annexed to a cogeneration plant (adapted)



The technology used for cogeneration has many attractions. It is incremental and modular, that is, it can start small as a 1–2 MW investment and then grow incrementally to 50–70 MW installations which lowers initial risk and facilitates local participation. It depends on a local supply of resources such as bagasse and other waste material from sugarcane after sugar or ethanol has been produced. It provides a secure power supply at cheaper rates along with enterprise creation potential in the form of local technology development. Further, its use will create jobs at the sugarcane plantation level.

Cogeneration generates greater thermal efficiency compared to traditional mills because less heat is rejected. It releases limited atmospheric emissions (particulate size <100 mg/ Nm^3, SO2 – almost non-existent with bagasse and in line with international regulations due to use of low-sulphur coal and NOx and the use of spreader-stoker technology). Since bagasse is a renewable fuel, it can be used to secure carbon credits. These characteristics of bagasse-based cogeneration provide a relief to global warming.

Energy status in Mauritius and role of bagasse-based cogeneration

Mauritius has limited renewable energy resources and no known oil, gas or coal reserves. Its main locally available energy resources are hydropower and sugarcane biomass (bagasse and cane tops and leaves). Hydropower and power exported to the grid from sugar factories (bagasse based) amounted to 22 per cent and 13 per cent respectively of power supplied to the public grid of the Central Electricity Board. The remaining 65 per cent of demand is met by imports. Hydro power is almost fully exploited through nine hydro stations.

The demand for electricity has increased due to rapid economic growth driven by export processing and international tourism. Residential power demand has also expanded with increased demand for electrical appliances and enhanced construction activities. These developments required additional investment by the public electric utility. The situation has changed in recent years. An alternative was considered comprising bulk purchasing of power from bagasse-cum-coal plants. In this alternative, private sector investment displaced public sector investment. Bagasse energy development was a logical component of the Sugar Sector Action Plan wherein government and the private sector participated in the restructuring process of the sugar industry. The enhanced use of by-products, such as bagasse for electricity production, was one of the major objectives. (See Table 17.1 for development of sugar sector reform initiatives and bagasse energy.)

Table 17.1. Sugar sector reform initiatives and bagasse energy

Year	Policy initiative	Emphasis on
1985	Sugar Sector Action Plan	Bagasse energy policy evoked
1988	Sugar Industry Efficiency Act	Tax-free revenue from sales of bagasse and electricity Export duty rebate on bagasse savings for firm power production Capital allowance on investment in bagasse energy
1991	Bagasse Energy Development Programme	Diversify energy base Reduce reliance on imported fuel Modernise sugar factories Enhanced environmental benefits
1997	Blue Print on the Centralisation of Cane Milling Activities	Facilitate closure of small mills with concurrent increase in capacities and investment in bagasse energy
2001	Sugar Sector Strategic Plan	Enhance energy efficiency in milling Decrease number and increase capacity of mills Favour investment in cogeneration units
2005	Roadmap for the Mauritius sugarcane industry for the 21st century	Reduction in the number of mills to 6 with a cogeneration plant annexed to each plant

Source: Mauritius Sugar Industry Research Institute

Mauritian sugar factories produce 525–575 tons of sugar from 5.2–6.8 million tons of sugarcane, which is grown on about 85 per cent of total arable land area. During the process of sugar production, about 1.8 million tons of bagasse is produced as a by-product (about one third of the sugarcane weight). There are currently 10 sugarcane mills operating with crushing capabilities ranging from 100 to 300 TCH (total cane harvested), all of which generates surplus electricity. Three power plants operate throughout the year using coal as a supplementary fuel during the off-season, whereas the remaining 7 are continuous power producers, only generating electricity from bagasse during the crushing season. Bagasse-cum-coal electricity reached 838 GWh in 2007 (347 GWh from bagasse), equivalent to 42 per cent of total electricity generated (Table 17.2).

According to information provided by Seebaluck et al. (2007), an average of 60 kWh per ton of cane crushed is generated for sale to the national grid. The amount of electricity exported using bagasse increased from 84 GWh in 1995 to 347 GWh in 2007. Figure 17.2 shows electricity generation for various configurations in cogeneration plants, along with electricity sale per ton of cane and electricity sale per ton of fibre. It is felt that there is further scope for energy generation from already commercialised state-of-the-art technology. From the same source of information, it is contended that the cogeneration of the total sugarcane biomass (tops and leaves) can further increase electricity generation by 350 GWh annually based on 50 per cent collection of the raw material from the sugarcane fields.

Table 17.2. Evolution of cogeneration in Mauritius (1995–2007)

Year	Cogeneration			Total		Bagasse %		Bagasse + Coal
	Bagasse	Coal						
	IC	GWh	GWh	IC	GWh	IC	GWh	% Total
1995	43	84	41	332	1047	13.0	8.0	11.9
1996	43	119	–	322	1151	13.0	10.3	10.3
1997	53	125	23	370	1252	14.3	10.0	11.8
1998	90	225	62	397	1365	22.7	14.2	18.7
1999	90	184	155	425	1424	21.2	12.9	23.8
2000	160	274	327	478	1527	33.5	17.0	39.4
2001	246	300	411	660	1657	37.3	18.1	42,9
2002	242	299	447	656	1715	36.9	17.4	43.5
2003	242	296	433	729	1840	37.0	16.1	39.6
2004	242	318	407	725	1923	37.0	16.5	37.7
2007	355	347	880	838	2160	42.4	16.1	56.8

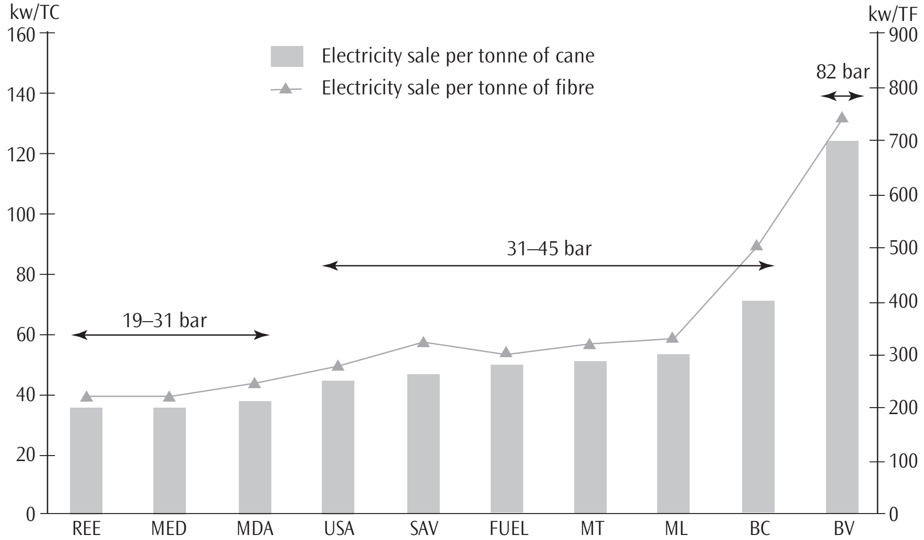
IC: Installed Capacity

Source: Information supplied from Mauritius Sugar Industry Research Institute

The other key features of cogeneration in Mauritius can be summarised as follows:

- It is attractive as it offers an alternative revenue stream to Mauritius's key economic sector – the sugar industry.

Figure 17.2. Surplus electricity yield from cane in Mauritius (2003)



Source: Seebaluck et al. (2007)

- Due to the developments on the cogeneration front, revenue from power sales for some sugar millers has recently exceeded that from sugar exports.
- It offers diversified sources of power thus providing protection against unstable and high oil price increases as well as drought-induced, hydropower crises.

Critical success factors

Government policies, particularly fiscal policy, tariff policy and funding initiatives have played major roles in the development of cogeneration enterprises and in the efficient utilisation of bagasse and other residues[1]. Moreover, it is important to recognise that the equitable distribution of revenue created during sugarcane production and generation of electricity has made a significant contribution to the growth of this renewable source of energy. Further stages in the evolution of policies regarding co-generation in Mauritius include:

- **Revenue sharing as an incentive package:** Revenue sharing increased incomes of all stakeholders including small sugarcane farmers. Cogen firms receive 50 per cent of the proceeds transferred via the Bagasse Transfer Price Fund (BTPF) in proportion to electricity exported to the national grid. Payment of income tax for 60 per cent of accrued proceeds is also exempted. The remaining 50 per cent of BTPF is distributed on a pro-rata basis between non-miller and miller planters on sugar production.
- **Facilitating a regular supply of bagasse:** Electricity generating plants had to rely on large amounts of bagasse from the satellite factories. These factories were pricing their bagasse on the price of coal and at the condensation stage of operations, resulting in a high imputed cost and price. This price had a negative impact on the financial viability of the energy project.

  These issues have been resolved through various measures, including:
  - consolidation of cane milling activities through an appropriate level of centralisation has allowed the sugar industry to realise economies of scale; and

    - the payment of income tax for 75 per cent of proceeds from sale of bagasse by a miller to one utility was also exempted.
- **Rationalisation of pricing and tariff structure:** A form of pre-defined and attractive feed-in tariff exists, which reduces risk to investors. Higher prices are offered to more efficient 'cogen' plants as a key incentive. Government played the 'honest broker' role in power purchase agreements and in setting the feed-in tariff which has helped to speed up negotiations and make them less acrimonious. Different prices were applied to the type of electricity being sold to the national grid. The underlying factors included the type of electricity provided (intermittent, continuous and firm power producer), investment in new or second-hand equipment, and changes brought to existing plants. For continuous power producers, 44 per cent of GWh price is indexed to changes in oil prices and the other 56 per cent is fixed. The electricity price of the electricity producer varies according to the plant's set up and is mainly indexed to the price of coal, cost of living indices in the country and foreign exchange rate fluctuations. The price of intermittent power was frozen so as to exert a disincentive on the adoption of less-efficient technologies in the renewable energy sector.
- **Fiscal measures to boost investment in 'cogen' plants:** The government introduced budgetary measures to make investments in energy projects more attractive. Investors were allowed to raise tax-free debentures for the generation of electricity from bagasse and for the modernisation of sugar factories. Furthermore, a performance-linked rebate on export duty was extended to producers of electricity firms who saved and used their own bagasse and also to millers selling bagasse to continuous power stations. A proportion of capital expenditure incurred in the installation of efficient equipment to enhance bagasse saving and energy generation is entitled to a refund of export duty payable. The other component of the programme was related to improvements in mill efficiency to produce surplus bagasse that could be provided to the planned power plant.
- **Long-term commitment** in terms of government policy support is critical. The Government of Mauritius executed two loans: one with the US government and the other with the Global Environment Fund implemented by the World Bank, with the explicit objective of ensuring the proper implementation of projects and enhancement of bagasse savings in the cluster of factories. The long-run commitment is displayed through the design of legislation and accompanying built in measures. Examples are the Sugar Sector Strategic Plan (2001–2005) which emphasises:
    - technology modernisation;
    - the diversification of products and by-products;
    - energy conservation and export of cogenerated energy to the national grid; and
    - a Roadmap for the Mauritius Sugarcane Industry for the twenty-first century (2005) as an extension of the current policy, laying more emphasis on global warming, climate change and the quality of the environment.
- **Public–private co-ordination:** The success of this programme can be attributed to the close collaboration between policy-makers, the sugar industry and public utilities. Investors' response to policy measures, fiscal incentives and stiff competition with traditional energy enterprises has been credible.

Other case studies and prospects

There are several issues involved in cogeneration of steam and electricity as part of sugar production. The development of bagasse-based electricity generation requires strong linkages between developments in the sugar industry and those in the power sector, as well as a greater emphasis on multipurpose benefits of base-load power from bagasse/coal plants. Brazil is one of the countries which has exploited its potential to solve the problem of power shortage (Searamucci et al., 2003). Moreover, sugarcane bagasse cogeneration technology is environmentally friendly because fossil fuel based electric generation emits carbon adding to global pollution. Brazil's net reduction of greenhouse gases due to the use of alcohol fuel for transportation and replacement of fuel oil by sugarcane bagasse has made it a net exporter of carbon credits.

Many islands are aiming to attain the status of a Renewable Energy Island (REI). An REI is an island that is 100 per cent self-sufficient from renewable energy sources, including transport (FED, 2000). For example, Faroe Island of Denmark became an REI because its only energy source is wind, which supplies 100 per cent of its electricity demand. In this context, sustainable community development plans to diversify energy sources, assume special significance[2]. These experiences are not limited to island countries. Brazil and India are two major non-island countries in this field[3]. Moreover, many countries in the tropical climate zone are in the process of diversifying their energy portfolios with the explicit objective of reducing their dependence on imported fuel and adopting clean environmental practices[4].

The sugarcane plant is known to have a high bioconversion efficiency of sunlight as a result of which a high amount of atmospheric carbon is fixed into biomass. The main interest until recently was to recover only sugar from this biomass. It can now be considered as a major renewable energy resource in sugarcane-producing countries. Strong government support, and a clear definition of its policy with respect to bagasse energy development is critical to the success of the set objectives of substituting bagasse for imported fossil fuels. The bagasse-coal power development policy and programme has multiple benefits in that it is associated with environmental advantages, it offers a diversified alternative, it is a secure source of power from locally available and renewable resource and it brings additional financial revenue to the cane sugar industry.

Conditions must be created to enable all the stakeholders to participate fully in the whole process, as well as to ensure a transparent flow of information among them. In this respect, the World Bank played a key role in providing the necessary support in areas in which the local stakeholders had little or no experience, and acted as an honest broker among the stakeholders. Prior to the start of a bagasse power plant, it is of utmost importance that a detailed feasibility analysis be done. A reliable cost estimate for a bagasse/coal plant and an agreement on a financing plan from the private entrepreneur must be standardised and made available. This would avoid delays in project implementation.

It has been indicated earlier that bagasse-based cogeneration activity is more prominent during the sugarcane season and it is linked with the seasonal sugar production stage.

Box 17.3. Global Sustainable Energy Island Initiative (GSEII)

Whereas Island 2010 aims to develop and promote 100 per cent renewable energy initiatives on islands within the European Union, the Global Sustainable Energy Island Initiative (GSEII) focuses on Small Island Developing States (SIDS) worldwide.
The Initiative is supported by a Consortium consisting of the Forum for Energy and Development (FED) and the four other international non-intergovernmental organisations: Counterpart International, The Climate Institute, Winrock International and the Organisation of American States. The GSEII has been organised to support the interests of all SIDS and potential donors by bringing renewable energy and energy efficiency projects, models and concepts together in a sustainable way for SIDS. The GSEII seeks to display national efforts to significantly reduce greenhouse gas emissions.

Global Objectives:
- To develop SIDS as sustainable energy nations;
- To establish donor support and private sector investment for the sustainable development; and
- To increase awareness of experiences, potential, and advantages of renewable energy utilisation and energy efficiency on SIDS and other island nations.

Regional and Island Nation Objectives:
The Caribbean:
- To develop St Lucia into a sustainable energy nation, thereby fulfilling its commitment made at COP5;
- To further develop sustainable energy plans for one or more Caribbean SIDS to become sustainable energy nations;
- To develop regional energy efficiency and renewable energy private business activities, including solar thermal photovoltaic, biomass, and wind turbines; and
- To establish funding schemes for large-scale dissemination of sustainable energy.

The Pacific Region:
- To develop wind-energy activities on Niue and one more island nation as regional door-opener projects;
- To develop sustainable energy plans for one or more SIDS to become sustainable energy nations;
- To develop regional energy efficiency and renewable energy private business activities, including solar thermal photovoltaic, biomass, and off-gird wind turbines; and
- To establish funding schemes for large-scale dissemination of sustainable energy.

The Indian Ocean:
- To develop a sustainable energy plan for one SIDS to become a sustainable energy nation.

During the off-season therefore, coal is used as a substitute for bagasse for electricity generation. The question is what happens to the products of combustion as emissions? In particular, how does bagasse-based cogeneration compare with electricity generation from coal?

While the main environmental argument is that bagasse is a renewable resource and its toxicity is minimal as compared with coal. Now if coal-based cogeneration is less environmentally friendly, it introduces a trade off between 'within' industry supply of electricity and supply of electricity from outside. If non-coal electricity is bought from outside and used in the sugar industry, it will be more environmentally friendly. The only problem is the uncertainties due to dependence on external supply. On the grounds of self-sufficiency in power generation, however, coal-based cogeneration has continued. It takes us to another important question that is how to ensure a supply of baggase the year round. Constraints on the year-round supply of bagasse deserve the attention of the sugar industry and policy-makers. It is worthwhile to consider the possibility of cultivating sugarcane for electricity generation also. The experimentation with such plans will depend on whether a country wants more sugar or more electricity from sugarcane. Sugar-exporting islands may go for such plans provided they have secured sugar export markets. Since, in recent years, European Union has decided to slash sugar prices for exports in a phased manner, it may not be feasible for island countries to think in terms of these alternatives.

The majority of the islands are endowed with agro-climatic conditions that are conductive to sugarcane production. With proper investment and management of this resource, high yields are potentially obtainable. Amongst other energy carriers, electricity from bagasse has been shown to be commercially viable in island states like Mauritius and Réunion which are devoid of any fossil fuel[5]. Islands can benefit in the development of this energy source under different schemes, such as Island 2010 and the Global Sustainable Energy Island Initiative (GSEII). Whereas Island 2010 aims to develop and promote 100 per cent energy initiatives in the EU, GSEII is a long-term plan focusing on SIDS world wide (see Box 17.3).

Exploitation of sugarcane bagasse as an annually renewable energy resource carries a high priority in the context of global warming. Apart from replication possibilities across countries and locations with a sugarcane base, it has the potential of strengthening the agro-industry sector because it is applicable to most forestry products such as wood/timber, pulp and paper, coffee, sisal, palm oil, tea, cocoa, and tobacco, among others.

Concluding remarks

Planning for sustainable energy resources will become a major preoccupation in islands, which have been heavily dependent on proceeds from sugar exports. Energy from sugar cane could provide a valuable cushion in terms of reduced oil import bills and in generating revenue for the sugar industry through the alternative use of sugarcane as a major input. This additional revenue source is of particular significance for Mauritius, which faced a 39 per cent cut in the sugar price from the EU in 2009.

Countries like Mauritius can also consider sugarcane cultivation only for electricity and ethanol. A shift from sugar to electricity and ethanol will also have an impact on the sugarcane variety that countries may chose to produce. There will be a trade-off between sugarcane with more sugar content and sugarcane with more bagasse. In this scenario, sugar can become a by-product because the major activity surrounding sugarcane may become bagasse-based electricity and ethanol production.

During the intercrop period when sugarcane bagasse is not in supply, coal is used as a substitute for bagasse for energy generation. The distinction between continuous and firm power producers should be eliminated by developing the storage capacity of unutilised excess bagasse during the season to be used during the off-season without involving coal in this electricity generation exercise. Moreover, the negative externalities due to coal used in cogeneration plants can be mitigated by finding alternative energy sources. The environmentally friendly alternatives worth considering are solar, wind and ocean currents. The substitution of coal by these energy sources would go a long way in meeting the objective of sustainable energy.

There is need to develop an aggressive renewable energy policy. Mauritius's coastal location and the availability of renewable energy sources, namely solar, wind, and possibly wave, and sugarcane bagasse should constitute an integrated renewable energy package. The success of bagasse-based energy cogeneration can provide avenues for Mauritius to move towards the objective of becoming an REI in the near future. Thus, the challenge of the demise of the sugar trade becomes an opportunity for saving small and island states in a new era of renewable energy production with, at its core, harvesting the yield of PPP (photosynthetic product of the planet).

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Notes

1 For a comprehensive discussion of policy measures aimed at efficiency, see Deepchand, 2001; Seebaluck et al., 2007.
2 See Dale et al., 2006, for community management of renewable energy in Prince Edward Island.
3 See Seebaluck et al., 2007, for some recent information on sugarcane bagasse cogeneration in these countries.
4 For an experience of a non-island country, Zimbabwe, with bagasse-based cogeneration, see Mbohwa, 2004; for Peru, see Dellepine et al., 2003.
5 For an excellent world wide overview of renewable energy on small islands, see FED 2000.