An Integrated System Analysis of Sugarcane Harvesting and Pre-Processing for Maximizing Sugar and Energy Production

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Abstract

Table sugar manufacture using sugarcane (*Saccharum officinarum*) is one of the major global industries that mainly contribute to supply sweetness and energy. World sugar production is predicted to grow by 2.1% annually. Higher increases are expected from the developing countries, with 79% of global production in 2025. Studying sugarcane cultivation and processing is essential combined with the environmental, social, and economic systems to increase thesystem's productivity while maintaining sustainability. Today sugar industries are facing many issuers while achieving sustainable development goals of development. Especially developing countries like Sri Lanka face problems related to labor productivity, mechanization, trash management, supply of quality sugarcane, and high moisture in bagasse for energy generations. Also, industry managers and policymakers face difficulties due to thesystem's complexity. Therefore, our main objective was to introduce a novel sugarcane harvesting system with the integration of energetically integrated processes for maximizing sugar and energy production and analyzing its dynamic effect by introducing a dynamic system model. We create three leading research to achieve this objective.

The objective of the first study was to minimize the energy required to process the cane and dry leaves harvesting (CDLH) for sugarcane while, at the same time, maximizing sugar production from cane and energy from dry leaves in Sri Lanka. The CDLH was conceptualized using a novel approach to optimize sugarcane harvesting to maximize biomass supply for energy production while reducing supply chain sugar-loss. The CDLH was investigated for manual harvesting capacity, energy consumption, sugar loss, and biomass energy potential. It was observed that CDLH consumed higher energy compared to the current practices of harvesting. However, the energy used for fieldwork was reduced because of the shifting of cane chopping and cleaning from the field to the factory. The low bulk density of the harvested cane of the CDLH system had a higher energy requirement in transportation. Comparatively, CDLH showed higher biomass energy potential and less sugar loss. High energy potential increases the energy potential to consumption ratio compared to the existing method. Therefore, the theoretical evaluation showed that the CDLH system could produce more than 20 kg of sugar and 879 MJ of electricity when processing 1 t of sugarcane.

Due to the implementation of CDLH, the sugar industry could have excess wet bagasse. Researchers have investigated the production of high-energy bio-oil and hydrochar from wet bagasse using hydrothermal liquefaction (HTL) on a laboratory scale. However, the HTL integrated bagasse utilizationsystem's energy efficiency at the industrial level is unknown, especially compared to baggage utilization practices. Therefore, our secondstudy's objective was to analyze an HTL integrated bagasse utilizationsystem's theoretical energy utilization compared to conventional bagasse utilization systems. A new bagasse utilization system was modeled combined with HTL. We used data from published articles and experiments to analyze the model. We simulated the model with different bio-oil and hydrochar yields and four heat recovery levels from the HTL final products. The results show that the novel process could exceed the electricity export rate compared to the conventional system, with high bio-oil and hydrochar yield at a 23 % heat recovery level. Further results show that the HTL integrated system with high bio-oil and hydrochar yields and 75 % heat recovery presented an electricity export benefit 170 % higher than the existing method in ideal conditions when using high-moisture bagasse.

Our third research developed a dynamic system model to support the sugarcaneindustry's decision analysis. We used this model to analyze the dynamics of implementation of CDLH combine with Sri Lanka sugar sector development policy (SSDP) compared to existing harvesting (CCH). We considered all thesubsystem's interrelation, such as sugarcane cultivation, sugar processing, energy generation, environment, social, and economic subsystem. This model combines all the system parameters dynamically as a series of events. We created a mental model, considering system thinking approaches. The mental model was transformed into stock-flow by introducing data, calculations and logical expressions. Then the model was simulated, adopting two scenarios such as implementing SSDP with CCH and CDLH.

The simulation results showed that implantation of SSDP combined with CDLH has many advantages, such as reducing the risk of labor shortage, availability of information for appropriate mechanization of sugarcane harvesting, increasing the sugar production, and increasing the farmers and workers income, increase the energy generation and less irrigation water requirements. However, the carbon dioxide release rate is slightly higher than the CCH in CDLH if the trash left in the field is not burnt or forced to degrade more rapidly in CCH. Because with CDLH, dry leaves are used for direct combustion to generate energy. Direct combustion releases carbon dioxide faster than trash degradation. This research concludes that. CDLH could increase sugar and energy production by enhancing the socio-economic condition of the sugarcane industry system. However, we used the data manually recorded by the sugar industry and experimented with theliterature’s data. Therefore, we recommended most parameters of this model to be connected to the real-time data acquisition system after integrating the IoT system. Integrating IoT system to this model to collecting data regarding harvesting, transportation, climatic, crop management, etc., are possible with available technologies. The industry can also adopt IoT applications to collect data regarding sugar production, energy generation, and emissions, etc. A combination of IoT with small changes to this model based on the system specifications could help to analyze the decisions of any sugar industry worldwide. However, the continuous model update is recommended to improve the accuracy.