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A mathematical model of SmartValley for estimation of contribution of biomass to the electrical generation

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***Abstract*—A mathematical model is presented for the estimation of the contribution of biomass to the generation of electricity for a valley as a geographical scope of application. It is considered that a valley has several species that are cultivated during the year and that have by-products of the harvest that we have considered as biomass that can be used for the production of electricity that would benefit the valley's inhabiting community. We have called this integration between population and crops SmartValley, which leads to the use of monitoring, control, management and planning among the different agricultural-energy actors. The cultivation and production of plants shows production variations during the year and throughout the years. For this, the mathematical model has as an essential part the data of usable biomass from which the electricity production estimate is made. A case study has been considered for the present study: a typical valley on the north coast of Peru, where rice crops are quite common, and; they have the potential to be used for electricity generation.**

Keywords—biomass, simulation, modeling, smart, valley.

I. Introduction

Life, as we know it, on our planet is due to an amount of energy received from our Sun in the form of photons at the rate of 1361 W/m^2. From this a tiny fraction is converted into biological cycles and temporarily stored in biomass and only an extremely small proportion of this fraction of biomass could finally be stored as fossil deposits such as coal, gas and oil. [5].

Biomass is a term used in the context of energy for a range of products which have been derived from photosynthesis. These can be recognized as garbage from urban areas and from agricultural and forestry processes [3]. That is, any material of recent biological origin and includes plant materials such as trees, grasses y agricultural crops [6]. The term biomass was introduced in 1975 to describe the natural materials used as energy sources [7]. Biomass has received considerable attention as a renewable energy resource after the oil crisis [1] occurred around 1975. However, 70% of the world used biomass as a source of energy in the 19th century [7].

The potential offered by biomass and solid waste to solve some of the world's environmental and energy problems is widely recognized [1]. The health of our biosphere and our atmosphere is totally dependent on the processes of photosynthesis. Every 300 years all the CO2 in the atmosphere is cycled through the plants, every 200 years all the oxygen and every 2 million years all the water [3].

Biomass has multiple ways of being processed to release some of the energy contained. There are four thermochemical methods of biomass conversion: pyrolysis, gasification, liquefaction and direct combustion [1]. Pyrolysis of biomass represents an important technology for the direct conversion of biomass into liquid fuels [6]. Gasification is the initial step for the production of Synthetic Natural Gas (SNG) from coal and dry biomass; it is the step of greatest conversion generating a gas product containing a mixture of condensable and permanent gases, as well as solid waste, and; It can be performed in different atmospheres and using different reaction agents [2]. The basic principles of biomass gasification have been known since the end of the 18th century and the first commercial applications are registered in 1850 [4].

The biomass potential is significant: Europe, Latin America and Africa have the potential to produce respectively 8.9; 10.9 y 21.4 EJ of biomass per year, with a corresponding equivalent of energy contained in 1.4×10^9 , 3.2×10^9 y 3.5×10^9 barrels of oil [6].

Biomass has traditionally been supplying a large fraction of energy needs in many developed countries, for example: in countries such as Finland (where it supplies 20% of energy needs), Sweden (16%), Austria (13%) and Brazil (23%). This is despite the fact that biomass energy density is low compared to fossil fuels. However, there are traditional technologies to increase bulk density biomes include baling, cubing and pelletizing [6].

Currently, climate change and the growing population force us to use energy resources and all possible materials efficiently in order to meet our growing need for energy. Therefore, the need for new energy systems using biomass leads to: (a) Developing systems to economically produce fuels and chemicals from biomass, which will help energy generating companies at to create their own sources, while simultaneously helping rural economic development; (b) Give added value to agricultural products which can economically improve many local industries; (c) The demonstration of full-scale biomass conversion systems to promote growth in the adoption of these technologies; (d) Biomass materials for energy production that stimulate the development of new products and technologies, as well as create new markets (with new jobs) with the potential to be exported; (e) Development of new biomass fuels; [7] among others.

Biomass energy can be harnessed either by direct use (such as in combustion for heat) or by conversion into a more useful and more valuable fuel such as a combustible gas or combustible liquid or products of high value for the chemical industry [1]

There are valleys around the world, those that have been created by rivers and where crops are made both for human consumption and for manufacturing, industry and commerce. They are also settled populations that depending on their location can contain from hundreds to hundreds of thousands of people. Therefore, it is of interest to propose a concept of adequate management of the available biomass resources so that they can be better utilized in the production of electrical energy for the populations living in the valley. We will call this concept SmartValley and we will describe it in this article with a case study of monoculture (one of the predominant crops on the north coast of Peru - as in other warm places - rice).

II. Biomass Production

A. Meaning and definition of biomass

The term biomass has traditionally been used in the field of ecology to refer to the total organic matter present in a given ecosystem and also in the area of industrial microbiology to refer to the amount of microorganisms produced in a microbial culture. In the field of renewable energy, the term biomass is used with two different meanings that the same denomination applies to the resource (raw material) and to the energy produced with its use: (a) In relation to the resource, it is understood by biomass “to any type of organic matter of recent biological origin”. It therefore comprises a very broad set of organic matter, ranging from products of plant, animal or microbial origin to the present in wastewater, sewage sludge or the organic fraction of urban solid waste. Fossil fuels and their derivatives (plastics and synthetic products) are excluded from this concept since, although they had a biological origin, their formation took place in remote times. (b) In the energy context, biomass is understood as a renewable energy source based on the energetic use of biofuels produced from biomasic type raw materials. Biomass has the character of renewable energy since its energy content comes, ultimately, from solar energy by plants in the photosynthetic process and accumulated in the bonds of organic molecules that form its biomass. Biofuels are the products from the transformation of biomass that are used for energy purposes, and may be, according to their physical state: solid, liquid or gaseous biofuels [8].

B. General considerations about of a Valley

A valley (from the Latin vallis) is a plain between mountains, a depression of the earth's surface between two slopes, with an inclined and elongated shape, which forms a hydrographic basin at whose bottom a river course is housed (river).

The assumed valley corresponds to a description framed in the presence of crop areas, a population located in one or several large urban centers and houses or groupings of small houses forming communities.

About the crops of the valley it can be mentioned that: (a) several crops are destined for the consumption of people (food), commerce (ornaments, gifts, flowers and the like) and for industrial production (wood and the like); (b) there are species that are grown once or several times during the year and some are annual and inter-annual crops; (c) it presents a variety of crops during the year according to the season that is present and the microclimate, in addition to other factors such as latitude, longitude, height and the surrounding geographical environment.

Of our interest are the crops for human consumption (food of the population) - for example: rice - which after harvest are processed to remove the bark, husk, leaves, stems (and the like) to be able to dispose them for consumption human. The material removed is primary biomass that serves for the elaboration of diversity of products and in which some of them serve as sources of thermal energy for the generation of electricity and heat.

C. General considerations on climate change

Governments across continents have committed under the 2015 Paris Agreement that calls for arresting the increase in global temperature below 2 degree Celsius (2DS) [9]. Climate change is a global process and all microclimates are affected.

The two main contributions to the cumulative emission reductions in the 2DS scenario during the 2013-50 period would come from the efficiency of final use of fuels and electricity (38%) and renewables (32%). Carbon capture and storage (CAC) would come in third place with 12% followed by nuclear energy with 7% [10].

In the world's agriculture, the degradation of land and water resources as a result of climate change can lead to a growing food deficit for the growing population of the planet, which will negatively affect food security. According to experts, the critical threshold is global warming at 2.50 C - below this threshold, changes in agricultural production may be insignificant, higher - possibly a significant reduction in volumes [11].

Therefore, our purpose is to make the valley's biomass included in the energy environment - mainly in the generation of electricity - which will lead to improved efficiency in the final use of fuels and electricity, as well how to predict and plan the amount of biomass necessary for carbon capture and storage. For this, a mathematical model is proposed and explained in the present work.

III. SmartValley's Mathematical Model

The mathematical model considers and emulates the production of biomass destined for human consumption for a year and considers those species in which, as a priority for food, it is grown in large quantities and harvests are achieved in a few months after planting (example: rice) , that is, several crops per year.

During the harvest, the biomass is removed from the valley floor under a behavior that has the form of a Gaussian curve in which the farmers are progressively starting the harvest until they have full production and then decreases as the biomass of the crop is depleted.

It is assumed that a certain amount of biomass is harvested every day. This biomass is then processed in which, if necessary, the inedible material is dried and removed, for example: in the case of rice, it is first dried and then obtained a certain amount of rice husk which can be burned to electric power generation.

The valley is considered to have a medium / high voltage power supply through power lines that transport electricity from the respective national power grid. Therefore, on each day it is possible to know (case a :) a characteristic demand curve standardized for any day or (case b :) a demand curve according to the register of readings made by meters properly disposed along the length and width of the Valley.

Be the subscript i the indicator of the crop from which biomass is going to be extracted for electric power production and is an integer of increasing value ($i = 1,2,3,...$) according to the amount of crops that can be used for this purpose.

Be $m_{i,k}$ the amount of crop mass i available per day k to be used in the production of electrical energy and has a calorific value $c_{p,i,k}$ and an electricity conversion efficiency equal to $\eta_{i,k}$. Instead of m_i a certain amount of electrical energy $E_{i,k}$ can be obtained, which if it is greater than the energy demanded per day D_k there will be a certain amount of biomass that is saved so that on the next day it will be used $m_{j,k}$. The amount of energy released from each biomass per day $E_{L,k}$ is determined using (1).

$$E_{L,k} = \left(m \cdot c_p \cdot \eta\right)_{i,k} \tag{1}$$

The crops needed to obtain a biomass m_i can be planned (considering that the harvest of each crop lasts a certain amount of days of the year), while the demand D_k has a random behavior. Different crops during the year will provide biomass that will be burned to produce electricity.

Our unit of measure of time will be the day number of the year represented by k which represents a domain from 1 to 365 days ($1 \le k \le 365$)and that increases in discrete values (whole numbers).

A representation of biomass production throughout the year i is expressed in (2) where Pa_i is the evolution of biomass production during each day of the year; p is the biomass harvest period number i ; ap is the starting day number of the harvest season p of the biomass i ; bp is the final day number of the harvest season p of the biomass i ; $m_{p,i,k}$ is the biomass production per day k within the period p for the biomass i ; $\prod_{ap}^{bp}(p,i)$ It is the function of rectangular window for each period p defined in (3).

$$Pa_i = \sum_p \left(m_{p,i,k} \Pi_{ap}^{bp}(p,i)\right) \tag{2}$$

$$\Pi_{aP}^{bP}(P,i) = \begin{cases} 0, & t < a, \\ 1, & a < t < b, \\ 0, & t > b \end{cases} \tag{3}$$

In a valley, the processing of biomass per day is carried out according to equation (4) by a certain number n of processing plants in which each, every day, contributes with m_r to the biomass available in the valley for the generation of electrical energy, information that each processing plant reports.

$$m_i = \sum_{r=1}^{n} m_r \tag{4}$$

Each valley is different. There are valleys in which crops are defined in certain weeks or months of the year and in other valleys (for example: in flat areas near the sea and in large mountain valleys) in which biomass production can be continuous throughout year.

Similarly D_k becomes the sum of residential, industrial and commercial loads located in the valley. Data can be obtained from readings in the electrical substations of the electricity distribution companies and make estimates of the consumer demand curve using various techniques, for example, as reported by [12].

IV. Simulationes y AnAlysis

Simulations are made according to the following criteria:

(a) the demand to attend is of the residential type that has a well-known and studied daily and monthly behavior as in [13];

(b) the crop to study will be rice;

(c) In the case of c_p of the rice husk there is a great diversity of reported values between upper and lower calorific value: 15.61 and 15.58 MJ/kg [14], from 13 to 14 MJ/kg [15], 13.731 MJ/kg [16], from 12.552 to 17.28 MJ/kg [17], 12.924 MJ/kg [18], 13.24 – 14.22 MJ/kg [19], 15 MJ/kg [20]; therefore, rice is considered to have a calorific value between

12.55 to 17.28 MJ/kg and that makes sense with the diversity in the degree of humidity from different rice treatment plants.

(d) For the η, [17] mentions that the performance of the cogeneration process through the gasification of residual biomass is 60.95%

(e) All of the above values will have a uniformly distributed random behavior included D_k defined together with Pa_i between a minimum and maximum value.

A. *Analysis of the agricultural energy environment under study*

In Fig. 1 it can be seen that each processing plant (PP) receives the production of a certain amount of agricultural producers (PA) in order to process and condition both the main purpose of biomass as a food product, for industrial use or similar, as well as to provide the surplus in adequate conditions to be sent to the electric power generation plant (PG). With the sum of the individual contributions of the PP, the total amount of biomass defined with (4) is achieved.

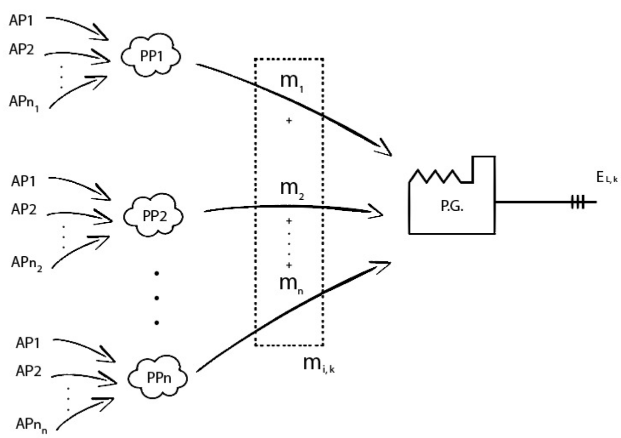

Fig. 1. Sequence of biomass transit through the agricultural energy model.

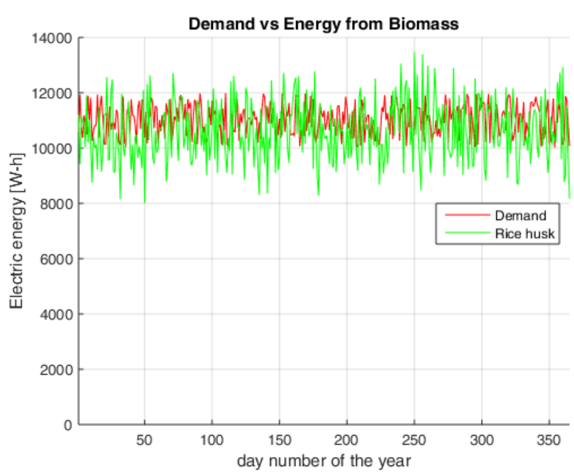

Fig. 2. Evolution of electrical demand and energy produced from biomass during the study period.

B. *Study scenario: Continuous production during the year*

In the North Coast of Peru (and other similar places) there are environmental conditions for planting rice throughout the year, with a slight decrease during some months considered with a lower temperature climate. This climate is characteristic due to its location near the equator. It has been considered in this case study a demand to attend and two PP.

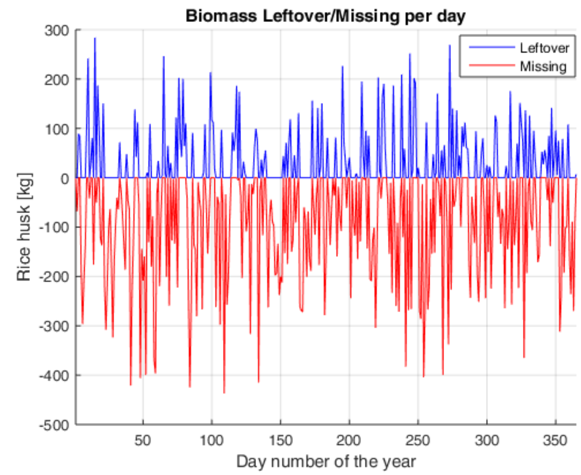

Fig. 3. Evolution of the leftover and missing biomass during the study period.

The simulations have been programmed and carried out in Matlab of MathWorks Inc.. The Eq. (5,6) correspond to the demand per day and the calorific value respectively, and; (7) and (8) is the biomass available to generate electricity provided by each PP. The rand command in Eq. (5-8) generates random numbers evenly distributed between 0 and 1.

$$D_k = 10000 + 2000 \times rand(1{,}365) \tag{5}$$

$$c_{p,k} = 12.55 + (17.28 - 12.55) \times rand(1{,}365) \tag{6}$$

$$m_{k,1} = 500 + 100 \times rand(1{,}365) \tag{7}$$

$$m_{k,2} = 500 + 200 \times rand(1{,}365) \tag{8}$$

The Fig. 2 shows on each day the energy requested by the electrical demand and the electrical energy generated from the biomass. In Fig. 3 shows the biomass (rice husk) missing to supply the demand and the surplus per day; in both cases it serves to plan its storage in order to arrange it in the coming days when there is missing biomass to supply the demand D_k .

V. Conclusions y Recommendations

Agricultural activity should not be detached from the energy activity of a small environment such as that of a valley, where biomass can be an important factor for the self-supply of energy in the area, its energy dependence is in close collaboration with the cultivated areas and the types of cultivation that are made. Therefore, having an adequate crop planning contributes not only to the food of the population and other economic activities, as well; biomass derivatives can make a great contribution to the energy balance of the valley.

New ways of managing the resources produced and consumed in a valley are necessary, accompanied by the form of government that gives the regulatory technical-legal framework for the different actors: natural and legal persons that are part of the economic and social development of the Valley . This leads to the exchange of information - daily, for hours or less depending on the times of harvest, processing and conditioning of the biomass - between the different actors of the valley, especially those of the food - energy chain: AP's, PP's and PG of the Valley. Likewise, with these data you can take trend studies to project in the short, medium and long term. The installation of meters, sensors, software, information and communications technologies are an essential part of the validity of the SmartValley concept.

Given the complexity of this topic and the peculiar characteristics that can be presented in each Valley, the authors recommend conducting multi-disciplinary research based on the availability of data according to the places where the concept of SmartValley can be tested.

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