Journal of Agriculture and Environment for International Development - JAEID 2021, 115 (1): 71-83
DOI: 10.12895/jaeid.20211.1394

# Decision criteria to tobacco biofuel production

ROSANA DE CASSIA DE SOUZA SCHNEIDER[1*], FERNANDO SANSONE DE CARVALHO[2], JORGE ANDRÉ RIBAS MORAES[3], ELPÍDIO OSCAR BENITEZ NARA[4]

[1,2,3,4] *University of Santa Cruz do Sul, Brazil*

**Correspondence details: rosana@unisc.br*

Submitted on: 2020, October 2; accepted on 2021, March 6. Section: Research Papers

## Abstract

This work presents a study to identify the potential of biofuel production from an energetic tobacco. The objective is to establish a priority scale under specific criteria for the possibilities of biofuels which have already been studied from various plants. This will provide a direction for research that aims to investigate biofuels, directing their efforts based on the priorities found. The priorities were obtained through multicriterial analysis, based on criteria chosen by the Saaty scale and defined with the Delphi method. After being analyzed in WebPROA software to determine the order of importance using three methods: Borda, Condorcet, and Copeland, all indicated that biodiesel and bioethanol are the two priority fuels for development of studies of energy tobacco biofuels.

***Keywords:*** *Energy tobacco. Biodiesel. Bioethanol. Multicriteria analysis.*

## Introduction

Brazil is the largest tobacco exporter in the world and its production is led by the south of the country, more specifically in Santa Cruz do Sul, regional center of the tobacco industry (Kist, Filter et al. 2018). For the tobacco leaf production, used in the cigarette industry, tobacco production in Brazil was 685,983 tons (97% in the southern region) in 2018, involving about 2.1 million people; of these 638,440 are directly involved in farming, over 40 thousand people are working in industrial roles and, finally, indirectly another 1,440,000 people are working in various related activities, earning an amount exceeding R$ 5.9 billion Tobacco growers' families in southern Brazil have a good socioeconomic level; 80% are between classes A and B, with an average per capita income of US $ 351.59 against US $ 203.10 as a general average in Brazil, according to the Brazilian Institute of Geography and Statistics (IBGE), and 90% are satisfied with working in agricultural activities and have planting technology that guarantees high productivity (Afubra 2019).

This agricultural scenario would be particularly good if there were no problems related to the purpose for which this tobacco is grown, that is, for the production of and use in cigarettes. Due to the constant pressures that this crop is receiving, from planting to the sale of cigarettes, a question arises: what other products can be obtained from tobacco itself and that can satisfy industrial diversification in tobacco growing regions? This is understood from the Framework Convention on Tobacco Control held in Geneva, Switzerland, where it was proposed to create a fund to diversify the productive or industrial sector (Kist, Filter et al. 2018).

Failing to consider the richness of this plant is an economic problem. As well as evaluating other plants for obtaining bioproducts, tobacco can also be investigated. Tobacco already provides other important inputs, such as interferon. According to (Mansour, Banik et al. 2018) in a promising study, using an unprecedented immunization vaccine with interferon gamma, obtained from the tobacco mosaic virus, it is possible to produce a protective immune response against a fatal disease in humans — the respiratory tularemia caused by the agent *Francisella tularensis*. Nowadays, due to the COVID-19 pandemic, some studies are carried out on new vaccines (Rosmino 2020).

In an easier route to diversification, it is also possible to obtain tobacco biofuels - the focus of this research. The use of biofuels, as recommended by research developed in various parts of the world, is represented in Figure 1, obtained from a search in databases (Web of Science and Scopus) from documents published in the last 10 years. In Figure 1, based on the words “tobacco” and “biofuel”, 3 clusters are identified that demonstrate that there are investigations in this area. In the clusters, we identified the central relevance of strategy, indicating that developing biofuels is a strategic action for the future, considering possible restrictions on the use of fossil fuels. Two important biofuels are also highlighted, represented by the clusters in green (bioethanol) and in blue (biodiesel). Red highlight is due to the cell wall and lignin, which are barriers to reaching fermentable sugars. It is also important to draw attention to the term impact, which is aligned with the two biofuels; the relationship between tobacco and other biofuels was almost non-existent compared to existing information on biodiesel and bioethanol. This reinforces the importance of assessing the potential for deriving these fuels from tobacco.

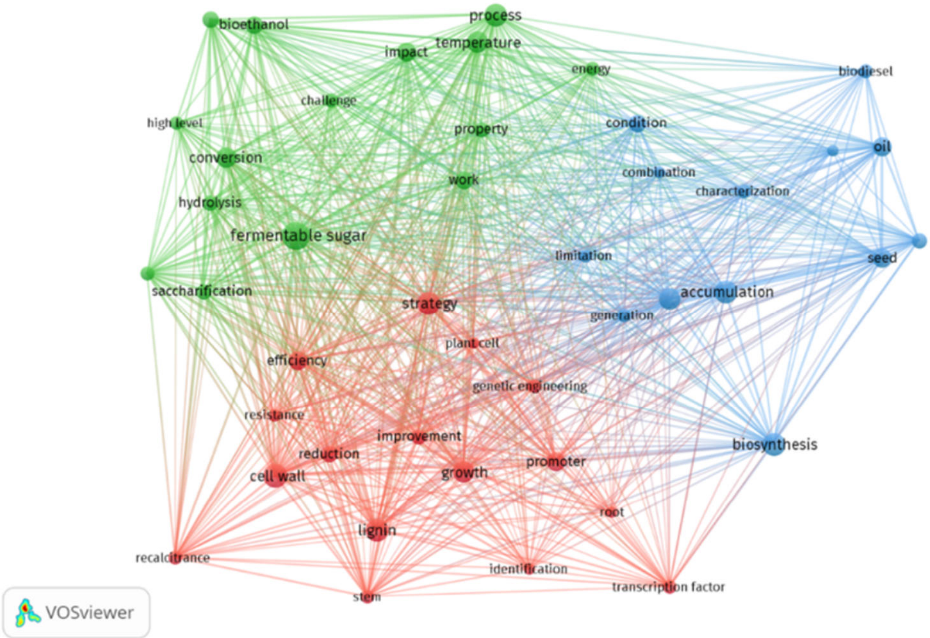


***Figure 1*** *– Clusters related to the relationship between tobacco and biofuels in a total of 192 articles from the Scopus and Web of Science databases, pre-processed in the VOSviewer software.*

To meet this reality, impacted by health of cigarette users, there is a pioneering biofuel project based on a new type of tobacco without nicotine, a variety called Solaris, known as “energy tobacco” — a result of genetic improvement accomplished by the team of

Prof. Corrado Fogher (Poltronieri 2016). Grisan, Polizzotto et al. (2016) and Poltronieri (2016) point out that the Italian company Sunchem Holding S.R.L. was responsible for the development of energy tobacco products and filed the international patent PCT / IB / 2007/053412, which points to the use of this tobacco for biofuel.

Tobacco plants for energy applications, unlike tobacco for the tobacco industry, maximize the production of flowers and seeds at the expense of leaf production. The varieties commonly used for cigarettes production are only suitable to produce leaves since they contain nicotine and flowering is not allowed. Therefore, only the Solaris variety is recognized to produce biofuel. According to Poltronieri (2016) the variety is extremely robust, capable of growing in various climates and soils and can be grown on marginal lands that cannot be used for food production. Besides that, it is possible to take advantage of the entire plant to produce biofuel. Poltronieri (2016) points out initiatives for the use of biokerosene from tobacco to produce sustainable biofuel for aviation, in a partnership formed by the companies South African Airways (SAA), Boeing, and SkyNRG, based in Amsterdam, in a project with potential to make aviation more environmentally friendly, while advancing rural development in southern Africa. He reports that SAA said that the cost of the tobacco-based product was the same as that of refined aviation fuel from fossil sources.

Gao, Chen et al. (2013) demonstrated a culture containing cellulose, hemicelluloses, and lignins that can be converted into bio-oil, fuel gas, solid carbon, and coal, by biomass pyrolysis. Várhegyi, Czégény et al. (2010) presented a thermogravimetric study of tobacco combustion using two mixtures of tobacco: Virginia and Burley. Yang, Li et al. (2011) carried out a study of the kinetics of tobacco pyrolysis performed with a dolomite/NiO catalyst. Boldrin, Balzan et al. (2013) and Živković, Veljković et al. (2017) showed the obtaining of bioethanol by fermentative processes from lignin-rich residue that, after treatment with hot water and filtration, can be used to generate electricity and heat through thermochemical processes or burning. The complete use of biomass is possible, however, they indicated that direct and indirect impacts on the environment must be controlled for sustainable biofuel production. The liquid fraction can be used to produce bio-hydrogen by dark thermophilic fermentation.

Grisan, Polizzotto et al. (2016) reported that Solaris was grown in Italy with excellent yield and adaptation to climatic conditions and after harvesting the seeds of energy tobacco, the other green tissues (stems and leaves) can be digested by anaerobic processes to obtain biogas. The feasibility of obtaining Solaris energy tobacco biogas after harvesting the seeds was also presented by Poltronieri (2016). Its economic value is given by the extraction of crude oil (energy production, biodiesel, market niche, and aviation fuel), oil extraction sludge (animal feed due to a good balanced), and fresh and dry biomass transformed into electricity and biogas.

In addition to the production of biofuels from energy tobacco in a region that is still a tobacco grower for cigarette production, with industries installed for many years, there is the industrial residue identified as powder and stalk tobacco, both rich in molecules that can be transformed together with energy tobacco (Shi, Li et al. 2019, Sun, Sun et al. 2020). The exploitation of stalks for ethanol production can be also a new alternative to small farmers that produce tobacco for cigarette purposes. According to de Souza Schneider, Anacker et al. (2017), 0.19 g $g^{-1}$ ethanol can be produced from milled tobacco stalks. These feedstocks were available to be use over 300,000 ha of land in Southern Brazil. In this sense, the potential of using tobacco for bioenergy can be summarized in Figure 2, considering the different parts of the plant destined for bioenergy and the industrial residues of the processed leaves of other cultivars.

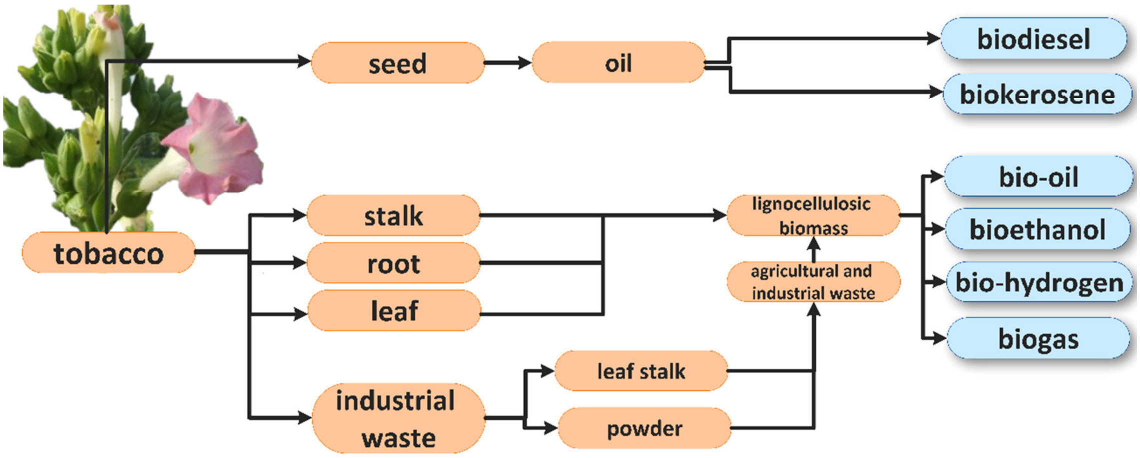


***Figure 2*** *– Flowchart for the use of energy tobacco and agroindustrial tobacco residues for the production of biofuels.*

Therefore, in order to choose the best ways to use tobacco for biofuels in view of the demands and research already carried out, as well as the potential for industrialization closer to the industrial biofuel, it is important to consider many aspects. The dispute concerning the conquest of larger slices of the consumer market stands out; the confrontation of the competition, the volume of investments and its adequate remuneration, the quality of the service or the product, the improvement of the environment, and social pressures are challenges for this choice. Maximizing results and minimizing expenditures, that is, making decisions based on established criteria, becomes increasingly important. In these scenarios, the technique that has obtained significant results in organizations is multi-criteria decision analysis (MCDA).

In the decision-making process, the MCDA tools combine stakeholder preferences and performance data of different technological alternatives to best satisfy the set of criteria identified for the complex tradeoffs involved in sustainability (Stoycheva, Marchese et al. 2018). In this sense, the best solution to a multicriteria problem is not that obtained by a complex mathematical method, but that preferred, accepted, understood, and defended by decision makers. Thus, we seek to investigate different scenarios to identify the best option. Techno-economic evaluations from the perspective of more technologies for production of biofuels is a crucial step for decision making in the development of bio-economy, avowed by Mandegari, Farzad et al. (2017) when they discussed sugarcane as a second-generation (2G) biofuel.

Likewise, Ranisau, Ogbe et al. (2017) highlighted the importance of decision policy in their study of gasification of corn stover in localization of biorefineries, capital investments, and production level. In this context, our work aimed to choose the best biofuel production options from energetic tobacco through a triangulation of three methods in order to establish a ranking of the biofuels based on the weights assigned to the selected criteria to identify the most suitable for production. With knowledge of the options comes potential for success in fuel production.

## Methodology

For decision making on the most important fuels for production from energy tobacco, a decision matrix was used based on data obtained in the laboratory, from experts, and from documents from databases about several biofuels from plants, considering oilseeds and those with lignocellulosic composition similar to tobacco. For this purpose, the Aggregated Ordinal Preferences tool WebPROA was selected. The decision matrix was composed of biofuels that can be obtained from energy tobacco and other varieties of tobacco (biodiesel, aviation biokerosene, bio-oil, bio-hydrogen, bioethanol, and biogas) cross-referenced in the matrix by four criteria: ease of obtaining, yield of biofuel, available technology, and necessary investment for production. The prediction of investments was according to the current technological requirements. The best possible uses for each part of the plant were considered, for example, the seeds could be used primarily for biodiesel and biokerosene, and the sludge from oil extraction for bio-oil.

To assign weight to the criteria, the Saaty and Delphi method proposed by (Dalkey and Helmer 1963) was used. In the Saaty method the classification of even values (2, 4, 6, and 8) were associated with intermediate judgments and the odd values were on a verbal scale of equal preference, moderate preference, strong preference, very strong preference, and absolute preference, defined on a numerical scale 1, 3, 5, 7, and 9, respectively. In Delphi, a more reliable consensus was reached among a group of experts, which has been widely used for sustainability applications (Terrados, Almonacid et al. 2009, Van Schoubroeck, Springael et al. 2019).

The data source definition used for the spreadsheet item was carried out by specialists meetings that present experience in the fields of: planting and harvesting, chemical and enzymatic tobacco biomass conversion to biofuel, fermentation of lignocellulosic material, engineering and thermochemical conversion.

Also, guidelines were considered in the expert discussion about the number of production steps, the need for equipment at each stage, pressure requirement, heating requirement, expected energy consumption based on types of equipment needed, use of microorganism processes, use of enzymatic processes, complexity of the final product, need for purification and extraction stages and the existence of equipment developed in Brazil. The possibility to produce 2 fuels in sequence was also discussed with respect to the facilities and technologies, however, the investment potentiality was not considered since there was not enough information for us, at the industrial level or research on a pilot scale.

The advantage of two seed harvest for biodiesel per crop was evaluated. In addition, it started with energy potential of tobacco only for application in the biofuels industry due to its genetic improvement. Transport distance was considered equal for all the biofuels types analyzed. Harvesting was defined as first harvesting two times the seeds and then the whole green mass. The cultivation stage was considered the same for all fuels.

In relation to the production cost, a technology mapping was carried out and the need for investments for the same scale was evaluated. Basic information for the discussion regarding the industrial production of biofuels from different feedstocks was obtained on the Reportlinker website (reportlinker.com) and reports from International Energy Agency (IEA). To compare paths, we also studied our previous results with biofuels (de Souza Schneider, Anacker et al. 2017, Fornasier, Gomez et al. 2018, Carvalho, Fornasier et al. 2019) and others documents from the last years (Souza, Santos et al. 2018, Garcia, Mattioli et al. 2019, Koistinen, Upham et al. 2019, Lee 2019, Yuan, Wei et al. 2019).

## Results and Discussion

The results were obtained after discussing with local experts how the Delphi method operates. Table 1 presents the results using the Saaty method where the weights were assigned to the criteria. The criteria were adopted for maximizing; that is, the higher the number the better. For the criterion called ease of obtaining, the Saaty scale from 1 to 9 was considered, with 9 being used for the biofuel that is easier to obtain according to a qualitative approach, decreasing the value as the difficulty increases. According to the Brazilian Agricultural Research Corporation (EMBRAPA), with regard to bio-hydrogen, there is little information on the process of obtaining it due to research in laboratories around the world being in an experimental phase. For this reason, they received the lowest score while the highest score was for biodiesel from the energy tobacco Solaris, which has already been produced on a large scale (by the company Sunchem) and is obtained directly from the oil extracted from the seeds.

In the yield criterion, the cubic meters of biofuel obtained from one hectare of cultivation of Solaris tobacco from the extracted oil or biomass generated was considered. Biokerosene was estimated from the potential soybean yield (500 L $ha^{-1}$) that produces half of that from tobacco oil, thus doubling the tobacco yield in relation to soybeans (Souza Júnior, Capdeville et al. 2017). For technology, the highest value (9) represents a technology already developed on an industrial scale and the smaller (1) represents technology which is feasible but not yet studied. For investments, it was based on an estimate of equipment needed to obtain biofuel on a production scale with value comparable to the necessary investments. Tables 2 to 4 show the ranking results obtained by each of the three methods: Borda, Condorcet, and Copeland, with their positions and the origins of the rankings.

***Table 1*** *– Decision matrix on the selection of biofuels to be produced from energy tobacco.*

| **Alternatives** | **Criteria** | | | |
|---|---|---|---|---|
| | **Facility** *MAXIMIZE* | **Yield** *MAXIMIZE* | **Technology** *MAXIMIZE* | **Investment** *MAXIMIZE* |
| Biodiesel | 9 | 9 | 9 | 8 |
| Biokerosene | 6 | 5 | 7 | 1 |
| Bio-oil | 3 | 7 | 3 | 5 |
| Bio-hydrogen | 1 | 1 | 1 | 3 |
| Bioethanol | 7 | 3 | 8 | 9 |
| Biogas | 8 | 2 | 5 | 7 |

***Table 2*** *– Borda method positions.*

| **Alternatives** | **Criteria** | | | | **Score** |
|---|---|---|---|---|---|
| | **Facility** *MAXIMIZE* | **Yield** *MAXIMIZE* | **Technology** *MAXIMIZE* | **Investment** *MAXIMIZE* | |
| Biodiesel | 1 | 1 | 1 | 2 | 5 |
| Biokerosene | 4 | 3 | 3 | 6 | 16 |
| Bio-oil | 5 | 2 | 5 | 4 | 16 |
| Bio-hydrogen | 6 | 6 | 6 | 5 | 23 |
| Bioethanol | 3 | 4 | 2 | 1 | 10 |
| Biogas | 2 | 5 | 4 | 3 | 14 |

***Table 3*** *– Condorcet method positions.*

| **Alternatives** | Biodiesel | Biokerosene | Bio-oil | Bio-hydrogen | Bioethanol | Biogas | Score |
|---|---|---|---|---|---|---|---|
| Biodiesel | 0 | 1 | 1 | 1 | 1 | 1 | 1º |
| Biokerosene | -1 | 0 | 0 | 1 | -1 | 0 | - |
| Bio-oil | -1 | 0 | 0 | 1 | -1 | -1 | - |
| Bio-hydrogen | -1 | -1 | -1 | 0 | -1 | -1 | 6º |
| Bioethanol | -1 | 1 | 1 | 1 | 0 | 1 | 2º |
| Biogas | -1 | 0 | 1 | 1 | -1 | 0 | - |

According to Table 1, the choice of the biofuel to be produced from tobacco corresponds to the lowest total number. The Borda method suggests, instead of choosing an option based on judgment, to create a ranking of the alternatives. The points attributed by the decision makers to each alternative were added and the alternatives with the lowest scores were chosen. Thus, with the Borda method, a sum of points was achieved and there is the advantage of simplicity (Bezerra Neto, Gomes et al. 2007, Valladares, Gomes et al. 2008). As this method is highly dependent on the results relating to the chosen evaluation set and the possibility of biased or targeted manipulations (Bouyssou, Marchant et al. 2006) the use of other methods was important, as shown in Tables 3 and 4.

***Table 4*** *– Copeland method positions.*

| **Alternatives** | Biodiesel | Biokerosene | Bio-oil | Bio-hydrogen | Bioethanol | Biogas | Score |
|---|---|---|---|---|---|---|---|
| Biodiesel | 0 | 1 | 1 | 1 | 1 | 1 | 5 |
| Biokerosene | -1 | 0 | 0 | 1 | -1 | 0 | -1 |
| Bio-oil | -1 | 0 | 0 | 1 | -1 | -1 | -2 |
| Bio-hydrogen | -1 | -1 | -1 | 0 | -1 | -1 | -5 |
| Bioethanol | -1 | 1 | 1 | 1 | 0 | 1 | 3 |
| Biogas | -1 | 0 | 1 | 1 | -1 | 0 | 0 |

With the Condorcet method, the classification was the same as the Borda method for the first two (biodiesel and bioethanol) and the third, fourth, and fifth position were not classified, as there was an intransitivity cycle. However, bio-hydrogen remained in the last position. This method required the decision maker who filled in Table 1 to order all alternatives according to their preferences, establishing overarching relationships. In other words, the alternatives were always compared two by two, which expressed the relationship between them (Boaventura Netto 2003).

The Condorcet method had the advantage of preventing distortions by making the relative position of two alternatives independent of their positions relative to any other. Thus, the method forced interactive interventions for the specialist, avoiding the paradigm of the optimum, which establishes a complete pre-judgment of the set of alternatives (Clımaco 2004). With this method, the disadvantage of intransitivity occurred (Table 3) where there was no classification of three items, leading to the “Condorcet paradox” or “Condorcet triplet”. This occurred when bio-oil is preferable to biogas, biogas is preferable to biokerosene, and biokerosene is preferable to bio-oil (Figure 3) (Bezerra Neto, Gomes et al. 2007, Valladares, Gomes et al. 2008).

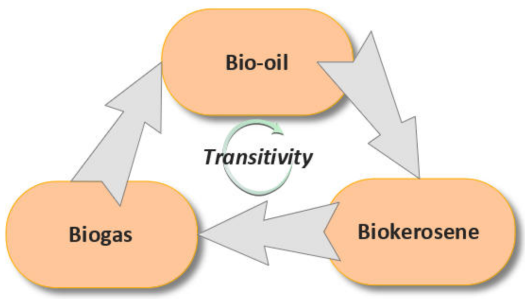


***Figure 3*** *– Condorcet triplet for the intransitivity of tobacco biofuels.*

With the Copeland method there was also an ordering with biodiesel and bioethanol in the first positions and then, in the third biogas, in the fourth biokerosene, in the fifth bio-oil, and finally in the sixth bio-hydrogen. The method, being derived from the Condorcet method, uses its advantages and calculates the sum of wins minus losses in a simple majority vote (Valladares, Gomes et al. 2008). In this way, there was no intransitivity and all options presented a different position.

Presenting the scenarios obtained with the three methods, it is understood that the production of biofuels from energy tobacco has the greatest possibility of success if the production of biodiesel and bioethanol is explored. As the scenarios are presented (Figure 4), it demonstrates the importance of the residual biomass also being used, which can be a path for biofuel development from this plant. The evolution of research and industrial production must follow a path that involves more technology and investments as it advances in an orderly manner. Lignocellulose has a great potential for biogas production, however, pre-treatment is important to fermentative processes since the mainly carbohydrate content is converted into intermediate acids, and mediates in the process of methane formation (Dahunsi 2019). Therefore, biodiesel and bioethanol become more attractive with advances in quality of production and services in industrial scale. For example, when used safflower (straw and seed) as a feedstock to biofuel production, the bioethanol was the main product, followed by biodiesel and biogas as byproducts (Khounani, Nazemi et al. 2019). On the other hand, plants with high oil content was used to biodiesel production and biomass could be applied to bioethanol and biogas production (Yao, Qi et al. 2013). In such systems, biogas is a byproduct before biodiesel or bioethanol production.

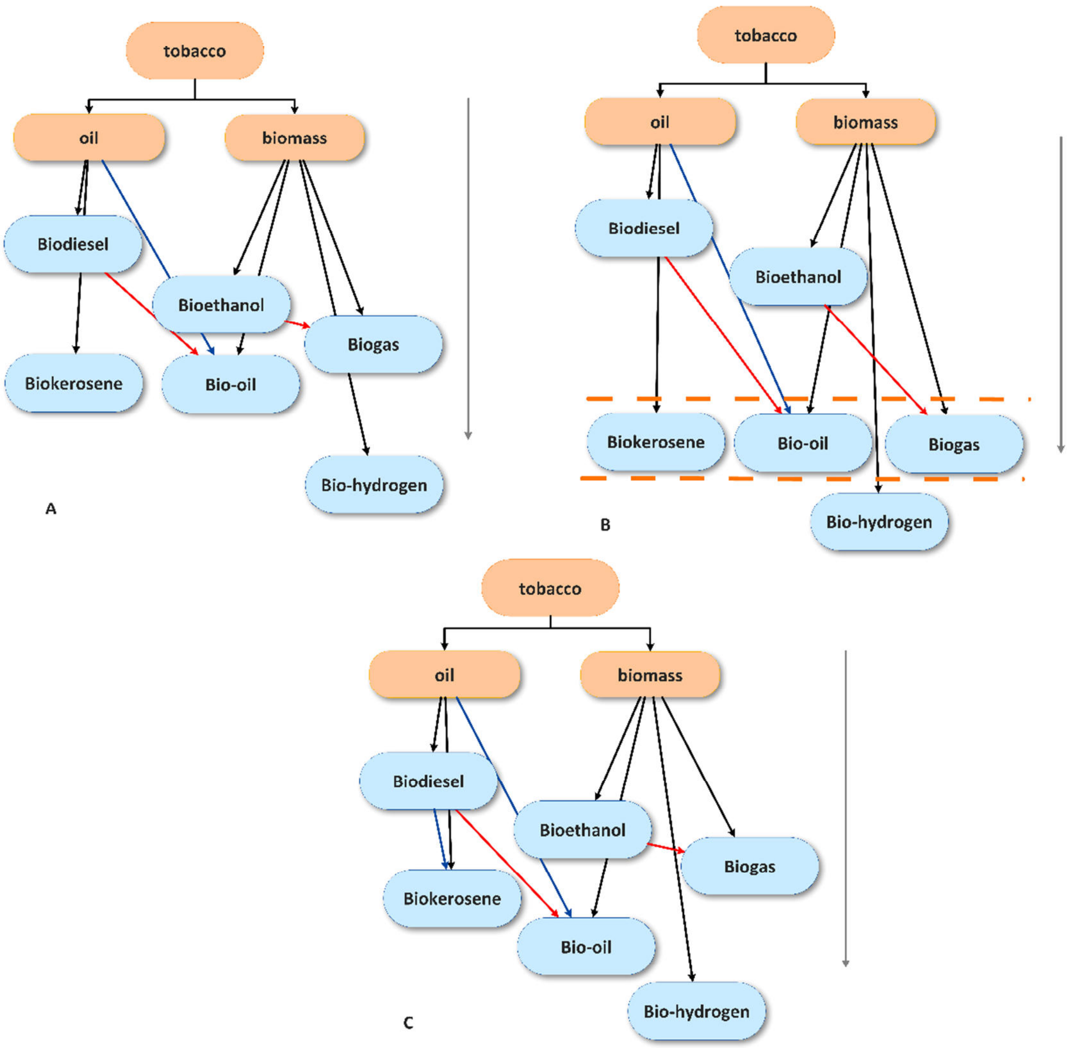


***Figure 4** – Production option scenarios based on Borda (A), Condorcet (B) and Copeland (C) methods.*

Therefore, in order to carry out the allocation of energy tobacco for use as biofuel, this work indicates which are the priorities for the use of the entire plant, pointing out that each part of the plant has a better, but not exclusive, use for each biofuel. The seeds should be used primarily for biodiesel, while the rest of the plant must be used to obtain bioethanol. These are the two main biofuels recommended to be obtained from tobacco according to this research, and it is essential to obtain both simultaneously depending on the different origins of the plant parts, thus defining the use of the entire plant and a better use of the species. In addition, the WebPROA tool simplified the multicriterial process of sorting, simultaneously adopting three methods (Borda, Condorcet, and Copeland) that can be accessed to give an order of priority according to the adopted criteria.

It should be noted that other aspects interfere in the decision, for example, safety and reliability, complexity, conversion efficiency, cost of production, operation and maintenance cost, and others (Liang, Ren et al. 2016). In addition, the transport of biomass to industry must be based on the principle of proximity between crops and industry, otherwise there would be a greater impact on the biofuel sustainability, even interfering with investments and cost (Lecksiwilai and Gheewala 2020). Process by-products can also be a benefit of the production of a given biofuel, as discussed for microalgae by Carneiro, Pradelle et al. (2017). However, discussions of these factors depend on pre-existing industrial information, and for the application of the multi-criteria decision methods for tobacco biofuel we did not have this information. Moreover, there is regional acceptability as a critical success factor. Agricultural producers that work with tobacco must be open to new opportunities.

## Conclusion

The application of multicriterial analysis proved to be effective to correlate the ease of obtaining each of the biofuels (biodiesel, bioethanol, biokerosene, bio-oil, bio-hydrogen, bioethanol, and biogas). In this work, first positions were identified for biodiesel and bioethanol, and therefore, it became simpler to direct studies involving the biofuels of energy tobacco, prioritizing the ordering to concentrate efforts on those that are, under various criteria, the chosen ones. It is worth noting that the sequence follows the current status quo and that technological advances in the future may enable the production of energy tobacco fuels, ensuring the diversification of culture. There are many aspects that interfere with the actual installation, however the multicriterial study has allowed us to focus on what is most appropriate to allocate efforts for the diversification by tobacco biofuels in a region recognized for excellence in tobacco production and which has the opportunity to diversify with a variety for biofuels.

## Acknowledgments

To Brazilian National Council for Scientific and Technological Development (CNPq) (310228/2019-0), and the Ministry of Science, Technology, Innovations and Communications (MCTIC) (01.0144.00/2010).

## References

Afubra. (2019). "Tobacco farming in South Brazil." from https://en.afubra.com.br/tobacco-farming.html#tobacco-production-in-brazil.

Bezerra Neto, F., Gomes, E. G. and Oliveira, A. M. d., 2007. Biological productivity in carrot and lettuce intercropping systems assessed by means of agroeconomic indicators and multicriteria methods. Hortic. Bras. **25**(2): 193-198. https://doi.org/10.1590/S0102-05362007000200013

Boaventura Netto, P. O., 2003. Grafos: teoria, modelos, algoritmos. São Paulo, Edgard Blücher.

Boldrin, A., Balzan, A. and Astrup, T., 2013. Energy and environmental analysis of a rapeseed biorefinery conversion process. Biomass Convers. Biorefin. **3**(2): 127-141. https://doi.org/10.1007/s13399-013-0071-9

Bouyssou, D., Marchant, T., Pirlot, M., Tsoukias, A. and Vincke, P., 2006. Evaluation and decision models with multiple criteria: Stepping stones for the analyst, Springer Science & Business Media.

Carneiro, M. L. N. M., Pradelle, F., Braga, S. L., Gomes, M. S. P., Martins, A. R. F. A., Turkovics, F. and Pradelle, R. N. C., 2017. Potential of biofuels from algae: Comparison with fossil fuels, ethanol and biodiesel in Europe and Brazil through life cycle assessment (LCA). Renewable and Sustainable Energy Reviews **73**: 632-653. 10.1016/j.rser.2017.01.152

Carvalho, F. S., Fornasier, F., Leitão, J. O. M., Moraes, J. A. R. and Schneider, R. C. S., 2019. Life cycle assessment of biodiesel production from solaris seed tobacco. Journal of Cleaner Production **230**: 1085-1095. https://doi.org/10.1016/j.jclepro.2019.05.177

Clımaco, J. C. N., 2004. A critical reflection on optimal decision. Eur. J. Oper. Res. **153**(2): 506-516. https://doi.org/10.1016/S0377-2217(03)00171-1

Dahunsi, S. O., 2019. Mechanical pretreatment of lignocelluloses for enhanced biogas production: Methane yield prediction from biomass structural components. Bioresource Technology **280**: 18-26. https://doi.org/10.1016/j.biortech.2019.02.006

Dalkey, N. and Helmer, O., 1963. An experimental application of the Delphi method to the use of experts. Manage. Sci. **9**(3): 458-467. https://doi.org/10.1287/mnsc.9.3.458

de Souza Schneider, R. d. C., Anacker, L. A., da Silva Szarblewski, M., da Silva, L. d. F. F., Moraes, M. S. A. and Corbellini, V. A., 2017. Bioethanol Production from Residual Tobacco Stalks. Current Journal of Applied Science and Technology: 1-9. https://doi.org/10.9734/CJAST/2017/37948

Fornasier, F., Gomez, J. F. C., de Carvalho, F. S., Schneider, R. d. C. d. S., Costa, A. B. d., Moraes, J. A. R. and Bravo, C. A. G., 2018. Biodiesel Production From Energy Tobacco.

Gao, W., Chen, K., Xiang, Z., Yang, F., Zeng, J., Li, J., Yang, R., Rao, G. and Tao, H., 2013. Kinetic study on pyrolysis of tobacco residues from the cigarette industry. Ind. Crops Prod. **44**: 152-157. https://doi.org/10.1016/j.indcrop.2012.10.032

Garcia, N. H., Mattioli, A., Gil, A., Frison, N., Battista, F. and Bolzonella, D., 2019. Evaluation of the methane potential of different agricultural and food processing substrates for improved biogas production in rural areas. Renewable and Sustainable Energy Reviews **112**: 1-10. https://doi.org/10.1016/j.rser.2019.05.040

Grisan, S., Polizzotto, R., Raiola, P., Cristiani, S., Ventura, F., Di Lucia, F., Zuin, M., Tommasini, S., Morbidelli, R. and Damiani, F., 2016. Alternative use of tobacco as a sustainable crop for seed oil, biofuel, and biomass. Agron. Sustainable Dev. **36**(4): 55. https://doi.org/10.1007/s13593-016-0395-5

Khounani, Z., Nazemi, F., Shafiei, M., Aghbashlo, M. and Tabatabaei, M., 2019. Techno-economic aspects of a safflower-based biorefinery plant co-producing bioethanol and biodiesel. Energy Conversion and Management **201**: 112184. https://doi.org/10.1016/j.enconman.2019.112184

Kist, B. B., Filter, C. F., Santos, C. E. d. and Carvalho, C. d. (2018). Anuário Brasilerio do Tabaco, Gazeta.

Koistinen, K., Upham, P. and Bögel, P., 2019. Stakeholder signalling and strategic niche management: The case of aviation biokerosene. Journal of Cleaner Production **225**: 72-81. https://doi.org/10.1016/j.jclepro.2019.03.283

Lecksiwilai, N. and Gheewala, S. H., 2020. Life cycle assessment of biofuels in Thailand: Implications of environmental trade-offs for policy decisions. Sustainable Production and Consumption **22**: 177-185. 10.1016/j.spc.2020.03.004

Lee, D.-H., 2019. Building evaluation model of biohydrogen industry with circular economy in Asian countries. International Journal of Hydrogen Energy **44**(6): 3278-3289. https://doi.org/10.1016/j.ijhydene.2018.09.069

Liang, H., Ren, J., Gao, Z., Gao, S., Luo, X., Dong, L. and Scipioni, A., 2016. Identification of critical success factors for sustainable development of biofuel industry in China based on grey decision-making trial and evaluation laboratory (DEMATEL). Journal of Cleaner Production **131**: 500-508. 10.1016/j.jclepro.2016.04.151

Mandegari, M. A., Farzad, S. and Görgens, J. F., 2017. Recent trends on techno-economic assessment (TEA) of sugarcane biorefineries. Biofuel Research Journal **4**(3): 704-712. 10.18331/brj2017.4.3.7

Mansour, A. A., Banik, S., Suresh, R. V., Kaur, H., Malik, M., McCormick, A. A. and Bakshi, C. S., 2018. An Improved Tobacco Mosaic Virus (TMV)-Conjugated

Multiantigen Subunit Vaccine Against Respiratory Tularemia. Front Microbiol **9**: 1195. 10.3389/fmicb.2018.01195

Poltronieri, P., 2016. Alternative energies and fossil fuels in the bioeconomy era: what is needed in the next five years for real change. Challenges **7**(1): 11. 10.3390/challe7010011

Poltronieri, P. 2016. Tobacco Seed Oil for Biofuels. Biotransformation of Agricultural Waste and By-Products. P. Poltronieri and O. F. D'Urso, Elsevier**:** 161-187.

Ranisau, J., Ogbe, E., Trainor, A., Barbouti, M., Elsholkami, M., Elkamel, A. and Fowler, M., 2017. Optimization of biofuel production from corn stover under supply uncertainty in Ontario. Biofuel Research Journal **4**(4): 721-729. 10.18331/brj2017.4.4.4

Rosmino, C. (2020, 01/06/2020). "Powerful properties: how tobacco is being used to fight COVID-19." Euronews, from https://www.euronews.com/2020/05/25/powerful-properties-how-tobacco-is-being-used-to-fight-covid-19.

Shi, W., Li, H., Zeng, X., Zhang, H. and Qin, X., 2019. The extraction of tobacco protein from discarded tobacco leaf by hollow fiber membrane integrated process. Innovative Food Science & Emerging Technologies **58**: 102245. 10.1016/j.ifset.2019.102245

Souza Júnior, M. T., Capdeville, G. d., Onoyama, M. M., de Souza, D. T., Santos, G. S., de Almeida, J. R. M., Lima, R. S. and Gambetta, R., 2017. Biodiesel e bioquerosene: o papel da Embrapa Agroenergia. Embrapa Agroenergia-Documentos (INFOTECA-E).

Souza, T. G. d. S., Santos, B. L. P., Santos, A. M. A., Souza, A. M. G. P. d., Correia de Melo, J. and Wisniewski, A., 2018. Thermal and catalytic micropyrolysis for conversion of cottonseed oil dregs to produce biokerosene. Journal of Analytical and Applied Pyrolysis **129**: 21-28. https://doi.org/10.1016/j.jaap.2017.12.010

Stoycheva, S., Marchese, D., Paul, C., Padoan, S., Juhmani, A.-s. and Linkov, I., 2018. Multi-criteria decision analysis framework for sustainable manufacturing in automotive industry. Journal of Cleaner Production **187**: 257-272. 10.1016/j.jclepro.2018.03.133

Sun, D., Sun, S. C., Wang, B., Sun, S. F., Shi, Q., Zheng, L., Wang, S. F., Liu, S. J., Li, M. F., Cao, X. F., Sun, S. N. and Sun, R. C., 2020. Effect of various pretreatments on improving cellulose enzymatic digestibility of tobacco stalk and the structural features of co-produced hemicelluloses. Bioresour Technol **297**: 122471. 10.1016/j.biortech.2019.122471

Terrados, J., Almonacid, G. and PeRez-Higueras, P., 2009. Proposal for a combined methodology for renewable energy planning. Application to a Spanish region. Renewable Sustainable Energy Rev. **13**(8): 2022-2030. https://doi.org/10.1016/j.rser.2009.01.025

Valladares, G. S., Gomes, E. G., Soares de Mello, J. C. C. B., Pereira, M. G., Anjos, L. H. C. d., Ebeling, A. G. and Benites, V. d. M., 2008. Análise dos componentes principais e métodos multicritério ordinais no estudo de organossolos e solos afins. Rev. Bras. Ciênc. Solo **32**(1): 285-296. https://doi.org/10.1590/S0100-06832008000100027

Van Schoubroeck, S., Springael, J., Van Dael, M., Malina, R. and Van Passel, S., 2019. Sustainability indicators for biobased chemicals: A Delphi study using Multi-Criteria Decision Analysis. Resour. Conserv. Recycl. **144**: 198-208. https://doi.org/10.1016/j.resconrec.2018.12.024

Várhegyi, G., Czégény, Z., Liu, C. and McAdam, K., 2010. Thermogravimetric analysis of tobacco combustion assuming DAEM devolatilization and empirical char-burnoff kinetics. Ind. Eng. Chem. Res. **49**(4): 1591-1599. https://doi.org/10.1021/ie901180d

Yang, Y., Li, T., Jin, S., Lin, Y. and Yang, H., 2011. Catalytic pyrolysis of tobacco rob: kinetic study and fuel gas produced. Bioresour Technol **102**(23): 11027-11033. 10.1016/j.biortech.2011.09.053

Yao, Z.-Y., Qi, J.-H. and Yin, L.-M., 2013. Biodiesel production from Xanthoceras sorbifolia in China: Opportunities and challenges. Renewable and Sustainable Energy Reviews **24**: 57-65. https://doi.org/10.1016/j.rser.2013.03.047

Yuan, Z., Wei, W., Wen, Y. and Wang, R., 2019. Comparison of alkaline and acid-catalyzed steam pretreatments for ethanol production from tobacco stalk. Industrial Crops and Products **142**: 111864. https://doi.org/10.1016/j.indcrop.2019.111864

Živković, S. B., Veljković, M. V., Banković-Ilić, I. B., Krstić, I. M., Konstantinović, S. S., Ilić, S. B., Avramović, J. M., Stamenković, O. S. and Veljković, V. B., 2017. Technological, technical, economic, environmental, social, human health risk, toxicological and policy considerations of biodiesel production and use. Renewable Sustainable Energy Rev. **79**: 222-247. https://doi.org/10.1016/j.rser.2017.05.048