Agrociencia

USE OF REAL OPTIONS TO EVALUATE THE PROFITABILITY OF BIOGAS PRODUCTION FROM STILLAGE IN THE TEQUILA INDUSTRY

Ana Karen **Santiago-Santiago**[1], Oscar Antonio **Arana-Coronado**[1*], Jaime Arturo **Matus-Gardea**[1], José de Jesús **Brambila-Paz**[1], Alma Lilia **Toledo-Cervantes**[2], Hugo Oscar **Méndez-Acosta**[2]

[1] Colegio de Postgraduados Campus Montecillo. Posgrado en Economía. Carretera México-Texcoco km 36.5, Montecillo, Texcoco, Estado de Mexico, Mexico. C. P. 56264.

[2] Universidad de Guadalajara. Centro Universitario de Ciencias Exactas e Ingenierías. Departamento de Ingeniería Química. Blvd. Marcelino García Barragán No. 1451, Guadalajara, Jalisco, Mexico. C. P. 44430.

* Author for correspondence: aranaosc@colpos.mx

Citation: Santiago-Santiago AK, Arana-Coronado OA, Matus-Gardea JA, Brambila-Paz JJ, Toledo-Cervantes AL, Méndez-Acosta HO. 2023. Use of Real Options to evaluate the profitability of biogas production from stillage in the tequila industry.
Agrociencia. doi.org/ 10.47163/agrociencia.v57i7.2991

Editor in Chief:
Dr. Fernando C. Gómez Merino

Received: March 18, 2023.
Approved: June 26, 2023.
Published in Agrociencia: October 18, 2023.

ABSTRACT

In Mexico, the tequila industry is the second most important economic activity within the alcoholic beverage industry, after the beer industry. Tequila vinasse is wastewater with a high organic load produced during the distillation of the fermented must of the blue agave (*Agave tequilana* Weber var. azul), which has a great impact on soils and water bodies in the tequila region. On the other hand, the decrease in fuel reserves causes instability in hydrocarbon prices, which makes it necessary to implement alternative fuel methods such as biogas. In this sense, it has recently been pointed out that the anaerobic digestion process is the most suitable for the treatment of tequila vinasse since it allows the removal of contaminating organic matter, together with the production of biogas that can be used *in situ* in the tequila industry. In this study, the financial feasibility of the production of biogas for self-consumption from tequila vinasse was calculated with the values achieved from a pilot system composed of a packed bed reactor (PBR) with technological and economic advantages to treat this waste. Profitability was evaluated over a 10-year production horizon (net present value $1 569 001) and was complemented with the Real Options methodology, taking into account price volatility and the option to expand. The results showed that the project is profitable with the 42.85 % biogas production expansion option. It is concluded that biogas production is financially feasible and it is possible to increase the profitability of the system by $6 325 109 if production is expanded.

Keywords: financial evaluation, investment, Real Options, binomial tree, volatility, expansion.

INTRODUCTION

Population growth, industrial development, and increased consumption of non-renewable resources have generated a large environmental impact and pressure on ecosystems (Vargas-Corredor and Pérez-Pérez, 2018). Nowadays, the development of new strategies and governmental plans should be focused on the 2030 agenda for sustainable development, which among its objectives seeks new alternative energy sources to reduce dependence on fossil fuels (Castro-Martínez *et al.*, 2012).

Bioenergy, which consists of the production and use of non-conventional energies, represents an alternative to this problem, as it reduces the environmental and economic costs of fossil fuels (Rodríguez-Hernández *et al*., 2016). The way modern economies consume and produce does not allow giving value to the waste that is generated, and when it is discarded, it causes pollution problems and ecological impact (Cadeza-Espinoza *et al*., 2017).

The tequila industry generates a high positive impact on Mexico's economy, mainly in the state of Jalisco, where most of the companies certified for tequila production are located. However, during distillation, vinasse is obtained, a waste liquid that constitutes a serious problem for the environment due to the large amount of organic matter present in it and the volume in which is generated (González-Rodríguez *et al*., 2020). On average, 10 to 12 L of vinasse are produced per liter of tequila produced. In 2021, a total of 527 million L of tequila were obtained, which implies an average of 5270 to 6324 million L of vinasse as waste (CRT, 2022).

With the exception of a few large tequila factories, most medium and small factories discharge vinasse directly into bodies of water and municipal sewage systems or directly onto the ground without receiving adequate treatment, generating water and soil contamination (CRT, 2019). The costs of pretreatment of the vinasse before disposal or disposal costs are absorbed by the tequila companies, making this an economic as well as an environmental problem.

Vinasse has potential as biomass for the production of biofuels such as biogas. One of the most suitable methods for biogas production is anaerobic digestion (AD) (López-Velarde *et al*., 2019). This has proven to be a technologically and economically advantageous method for treating vinasse (Espinoza-Escalante *et al*., 2009). Anaerobic digestion as an alternative for effluent treatment represents an alternative for the substitution of fossil fuels and offers solutions to wastewater pollution such as distillery vinasse (Lorenzo-Acosta *et al*., 2015).

Biogas in Mexico is capable of substituting fossil fuels in power generation. It contains approximately 60 % methane and 40 % carbon dioxide, and its calorific value makes it a competitive fuel. Biogas production allows vinasse to stop being a pollutant and become an abundant and cheap raw material for energy production (González-Rodríguez *et al*., 2020). Real Options is a financial evaluation methodology that considers the operational flexibility that the manager has throughout the life of the project, which can defer, abandon, follow, expand, reduce, or change (Brambila-Paz *et al*., 2013).

Cisneros-López *et al*. (2020) mention that Real Options are a suitable tool for the evaluation of investment projects in the renewable energy sector, which present scenarios under conditions of risk and uncertainty. There are technological advantages for the production of biogas from tequila vinasse; however, its economic evaluation in situ in the tequila industry with Real Options has not been documented, making it necessary to carry out this type of project.

The objective of this research was to calculate the financial feasibility of biogas production for self-consumption from tequila vinasse with the values obtained from a pilot system consisting of a packed bed reactor (PBR). The hypothesis was that the production of biogas from tequila vinasse is financially feasible and increases the profitability of the project by increasing the production volume of the plant.

MATERIALS AND METHODS

A financial investment project was developed and the technical data of a laboratory-scale packed bed anaerobic digester (Arreola-Vargas *et al.*, 2018), a producer of biogas from tequila vinasse, were taken as a basis. The reactor is located at the University Center of Exact Sciences and Engineering (CUCEI) of the University of Guadalajara, Mexico.

In March and July 2021, costs and benefits of biogas production were collected through two semi-structured interviews with the researchers in charge of the pilot plant, which included general process data such as biogas production rate, methane yield, operating time, instruments, actuators, equipment, and materials required for process monitoring and operation, as well as reagents, inputs, consumables, and electricity costs. Other data researched and captured were related to the financing of the plant and the sale of carbon credits (Table 1).

The price of biogas in Mexico is unknown, so an approximation of this variable was obtained by comparing the prices of fuel oil, since this is the fuel to be substituted in the boilers to produce steam in the tequila plants. All economic values are expressed in constant 2021 values and are based on a parity of MXN 20.28 per USD (BANXICO, 2023).

Biogas production with reactor volumes of 7 and 10 m^3 was estimated from the values achieved in the 445 L anaerobic digester, with a feed flow of 99 L d^{-1} of water and

Table 1. Revenue and cost breakdown of biogas production with a reactor volume of 7 m^3.

Concept	0	1	2	3		8	9	10
Initial investment†	4 736 621				--			
NPV	1 569 001				--			
Project benefits¶		2 925 879	2 925 879	3 268 730	--	3 268 730	3 268 730	5 535 013
Variable costs§		239 356	239 356	239 356	--	239 356	239 356	239 356
Fixed costsᵖ	306 803	804 453	804 453	804 453	--	804 453	804 453	804 453
Financial costs		329 045	274 064	214 135	--			
Incremental working capital		1 340 897			--			
Amortization		610 899	665 880	725 809	--			
ISR¤		381 135	397 630	518 464	--	582 704	582 704	582 704
PTU††		127 045	132 543	172 821	--	194 235	194 235	194 235

†Land, 7 m^3 PBR system, gas holder, computer, laboratory equipment; ¶Heat savings per year 34 861 310 Kca at a fuel oil heat energy price of 0.038 (\$ Kca^{-1}), vinasse treatment savings 276 249.17 L at a price of 5.7 (\$ L^{-1}) and CO_2 sale 7.86 (\$ Mg) with a production of 102 719.67 (Mg CO_2 eq a); §Tequila vinasse, industrial grade NaOH, water, bicarbonate, electric power for plant operation; ᵖlaboratory and office consumables, monitoring reagents, salaries, plant maintenance and insurance, monitoring administration and validation of CO_2 sales, telephone line and internet service; ¤ Income tax of 30 %; †† Employee profit sharing of 10 %.

49 L d^{-1} of vinasse and a production of 950 L d^{-1} of biogas, assuming that the yield and chemical oxygen demand (COD) removal values will not change as the process is scaled up. Biogas production was evaluated based on a reactor with a volume of 7 m^3, a feed flow of 1.55 m^3 d^{-1} of water and 0.77 m^3 d^{-1} of vinasse, and a production of 14.94 m^3 d^{-1} of biogas in an operating time of 355 days per 24 hours, considering a total of 10 days of shutdown for annual maintenance.

The traditional project financial evaluation approach was used, obtaining the Net Present Value (NPV) at a discount rate of 10 %, which considers the bank rate at 2021 of 9 % and project risk of 1 %; the financial analysis was elaborated under a 10-year projection. According to Baca (2013), the NPV formula is as follows:

$$VAN = - I + \sum_{i=1}^{t} \frac{b_i - c_i}{(1 + \partial)^t}$$

where I is initial investment, b_i profit at time i, c_i cost at time i, ∂ discount rate, and t time or investment horizon. If NPV ≥ 0, the project is accepted.

The Internal Rate of Return (IRR) was determined according to Baca (2013), this is defined as the discount rate that makes the NPV of a project equal to 0, and it indicates the maximum interest rate that the project generates:

$$0 = - I + \sum_{i=1}^{t} \frac{b_i - c_i}{(1 + \partial)^t}$$

The financial indicator of Benefit/Cost Ratio (B/C) was calculated based on the formula used by Cisneros-López *et al.* (2020):

$$R\frac{B}{C} = \frac{\sum_{i=0}^{n} FI_i}{\sum_{i=0}^{n} FS_i}$$

where B is benefit; C is cost, FI is discounted income flow, FS is discounted cash flow, i is the initial period, and n is number of periods. The ratio indicates that for each peso invested, there will be benefits when this ratio is greater than one, and therefore the project is accepted.

The statistical series of fuel oil prices from 2002 to 2017 was obtained from the Ministry of Energy (SENER) and from 2018 to 2021 from Petróleos Mexicanos (PEMEX). The price used for the traditional NPV calculation was \$9.15 L^{-1}, which corresponds to 2021. Prices were deflated with the Consumer Price Index base 2Q July 2018 = 100 reported by the Bank of Mexico (BANXICO, 2021) (Table 2).

The analysis was complemented with the Real Options methodology, which takes into account price volatility, to determine the financial convenience of increasing the

Table 2. Historical fuel oil price data used to calculate price volatility and Real Options.

Year	Nominal price of fuel oil ($ L^{-1})	Real price of fuel oil ($ L^{-1})
2002	1.60	3.98
2003	1.77	4.12
2004	1.91	4.13
2005	2.30	4.74
2006	3.26	6.35
2007	3.31	6.24
2008	5.60	9.89
2009	4.78	8.14
2010	6.13	9.81
2011	7.92	12.11
2012	9.32	13.61
2013	8.26	11.24
2014	7.88	9.95
2015	4.85	5.98
2016	3.32	4.05
2017	5.77	6.27
2018	7.20	7.07
2019	5.26	5.03
2020[†]	6.05	5.86
2021[¶]	9.15	8.04

Source: Own elaboration with information from [†]SENER (2018) and [¶]PEMEX (2022).

production volume. The methodology used by Santiago-Santiago *et al*. (2020) was used to calculate the binomial trees with the Real Option to expand. The continuous rate of movement of real fuel oil prices was used to measure risk:

$$\ln \frac{P_t}{P_{t-1}} = r_t$$

where r_t is the rate of continuous movement of the real price, In is the natural logarithm, and P_t is the real price in period t.

The continuous rates of price movement were used to estimate their mean and standard deviation, which are measures of price trend and volatility:

$$\mu = \frac{\sum_{t-1}^{r} (r_t)}{n}$$

$$\alpha = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2}$$

where n is the number of real prices, x_I is the price of each period, and $\bar{x}$ is the average of x_i.

With the standard deviation of the prices, the scenarios of the binomial tree were formed:

$$u = e^{\alpha}$$

$$d = e^{-\alpha}$$

where *u* is the value the project takes when prices increase and *d* is the value the project takes when prices decrease.

The value of the project may increase or decrease, and the probability of this occurring is as follows (Santiago-Santiago *et al*., 2020):

$$p = \frac{(1 + l) - d}{u - d}$$

where p is the probability that the value of the project will increase, l is the risk-free interest rate, *u* is what increases the value of the project, and *d* is what decreases the value of the project.

Once the nodes of the binomial tree have been calculated and the biogas horizon is available, the data is brought to present value through a recursive process. The definition of the present value of the cash flow, in this case V_0, was used as a starting point, and the probability was considered a weighting factor:

$$V_0 \frac{P(Vu) + (1 - p)\,Vd}{1 + r}$$

where V_0 is the initial present value, p is the probability that the project will do well, *Vu* is the value of the upper node, (1 - *p*) is the probability that the project will do poorly, *Vd* the value of the lower node, and r is the risk rate.

Real Options lead to flexibility in decision-making that does not require the realization or cancellation of a project, considering the total NPV composed of the traditional NPV plus the NPV of the Real Option. A Real Option is the right, but not the obligation, to exercise an action that has an effect on a real asset at a predetermined cost and time (Ortíz-Rivera *et al*., 2020). Mascareñas-Pérez *et al.* (2004) indicate that the total net present value of the project will be equal to the traditional net present value plus the value of the Real Option of producing biogas from tequila vinasse:

$$NPV_{TOTAL} = NPV + OR$$

where NPV_{TOTAL} is the Total Net Present Value, NPV is the Net Present Value calculated in the traditional way, and *OR* is the Real Option.

RESULTS AND DISCUSSION

The biogas plant is important in the treatment of vinasse. It greatly reduces the environmental impact and provides economic and energy advantages (González-Rodríguez *et al*., 2020). When evaluating the costs and benefits of the biogas production project with a reactor volume of 7 m^3, discounted at an annualized rate of 10 % and projected over 10 years, a positive NPV ($1 569 001) is obtained, and the project is therefore accepted (Table 3).

Table 3. Updated revenues, costs, and cash flow for the production of biogas from tequila vinasse with a reactor volume of 7 m3, in Mexican pesos 00/100 M.N., with data from 2021.

Years/ Concept	Projected income	Projected costs	Cash flow
0		4 736 621	-4 736 621
1	2 659 890	3 427 109	-0 767 219
2	2 418 082	2 055 354	362 728
3	2 802 387	2 129 156	673 232
4	2 547 625	1 978 464	569 161
5	2 316 022	1 793 513	522 509
6	2 105 475	1 117 838	987 637
7	1 914 068	1 035 026	879 042
8	1 740 062	923 833	816 229
9	1 581 875	839 848	742 027
10	2 297 907	777 630	1 520 276
NPV			1 569 001
IRR			14 %
RB/C			1.08

The net profit considers the increase in annual revenues through the sale of biogas ($1 337 446.48), reduction of costs generated by the disposal of tequila vinasse ($1 588 432.71), and carbon credits ($807 438.24). As indicated by Lorenzo-Acosta *et al*, (2015), biogas production projects from distillery vinasse can be supported economically through CO_2 bonus sales agreements.

The results obtained in the nodes of the binomial tree in which the volatility of fuel oil prices is considered show the value of the project over the years when prices rise or fall (Table 4).

Table 4. Dynamics of the value of the biogas production project (in thousands of pesos).

0	1	2	3		8	9	10
1 569 001	2 059 171	2 702 473	3 546 749	--	13 809 425	18 123 607	23 785 576
	1 195 513	1 569 001	2 059 171	--	8 017 474	10 522 201	13 809 425
		910 931	1 195 513	--	4 654 783	6 108 977	8 017 474
			694 091	--	2 702 473	3 546 749	4 654 783
				--	1 569 001	2 059 171	2 702 473
				--	910 931	1 195 513	1 569 001
				--	528 868	694 091	910 931
				--	307 050	402 975	528 868
				--	178 267	233 959	307 050
				--		135 832	178 267
				--			103 498

Profitability indicators $\sigma = 0.27$, $u = 1.31$, $d = 0.76$, p = 0.52, 1-p = 0.47. Elaborated with data from SENER (2018) and PEMEX (2022).

By complementing a project considering the Real Options approach that considers the flexibility of decisions when there is volatility and uncertainty in the profitability of investments, the value of the project will increase by increasing profits or lessening losses, which is confirmed by those presented by Brambila-Paz *et al*. (2013), Valencia-Sandoval and Zetina-Espinosa (2016), Cadeza-Espinoza *et al*. (2017), Cisneros-López (2020), Ortíz-Rivera *et al*. (2020), and Pérez-Cerecedo *et al*. (2020).

Based on the volatility of fuel oil prices, the project is open to the possibility of a maximum profit of $23 785 576 and a minimum profit of $103 498. For the project with a production expansion of 42.85 % with a reactor volume of 10 m^3, the NPV was $6 325 109, thus, the project is also accepted (Table 5).

Table 5. Dynamics of the value of the biogas production project with 42.85 % expansion (in thousands of pesos).

0	1	2	3		8	9	10
6 010 282	6 325 110	8 301 128	10 894 471	--	42 418 111	55 669 889	73 061 636
	6 325 110	8 301 128	10 894 471	--	42 418 111	55 669 889	73 061 636
		4 819 467	6 325 110	--	24 627 099	32 320 814	42 418 111
			3 672 231	--	14 297 996	18 764 812	24 627 099
				--	8 301 128	10 894 471	14 297 996
				--	4 819 467	6 325 110	8 301 128
				--	2 798 085	3 672 231	4 819 467
				--	1 624 512	2 132 023	2 798 085
				--	943 159	1 237 810	1 624 512
				--		718 647	943 159
				--			547 579

Positive values were obtained with the expansion option, suggesting that it is feasible to invest in the expansion of the reactor capacity volume for biogas production. The total NPV value with the Real Option value of the expansion decision shows a higher profit, making it profitable (Table 6).

Table 6. Project profit with the expansion option.

NPV ($)	OR ($)	NPV_{TOTAL}($)
1 569 001	4 441 281	6 010 282

NPV = Net Present Value; OR = Real Option; NPV_{TOTAL} = NPV + OR.

This result is similar to that reported by Valencia-Sandoval *et al*. (2010), who showed that the Real Option of expanding cactus production to 6 ha generates an increase in income year by year. Pérez-Cerecedo *et al*. (2020) indicated that there is a financial incentive to expand commercial generic egg production for medium and large producers.

CONCLUSIONS

The evaluation of the project with the Real Option of expansion through the use of binomial trees incorporating price volatility shows that the total net present value of the project increases considerably, making the project more profitable, so it is convenient to invest in the increase of the reactor volume by 42.8 %. The production of biogas through the anaerobic digestion method in a packed bed reactor (PBR) for the treatment of vinasse generated from the distillation of tequila, evaluated with the Real Option of expansion to invest in an increase in production, was feasible and represents a financially profitable alternative. The integral use of tequila vinasse could open up growth prospects for tequila producers and society through the establishment of biogas plants.

ACKNOWLEDGMENTS

To the Consejo Nacional de Ciencia y Tecnología (CONACYT) for grant 760384 awarded to the first author.

REFERENCES

Arreola-Vargas J, Snell-Castro R, Rojo-Liera NM, González-Álvarez V, Méndez-Acosta HO. 2018. Effect of the organic loading rate on the performance and microbial populations during the anaerobic treatment of tequila vinasses in a pilot-scale packed bed reactor. Chemical Technology and Biotechnology 93 (2): 591–599. https://doi.org/10.1002/jctb.5413

Baca G. 2013. Evaluación de proyectos (Séptima edición). McGraw Hill: Ciudad de México, México. 371 p.

BANXICO (Banco de México). 2021. Principales índices mensuales. Sistema de información Económica. Banco de México. Ciudad de México, México. https://www.banxico.org.mx/SieInternet/consultarDirectorioInternetAction.do?accion=consultarCuadro&idCuadro=CP154&locale=es (Retrieved: December 2021).

BANXICO (Banco de México). 2023. Serie histórica diaria del tipo de cambio peso-dólar. Banco de México. Ciudad de México, México. http://www.banxico.org.mx/.México (Retrieved: December 2022).

Brambila-Paz JJ, Martínez-Damián MA, Rojas-Rojas MM, Pérez-Cerecedo V. 2013. La bioeconomía, las biorrefinerías y las opciones reales: el caso del bioetanol y el azúcar. Agrociencia 47 (3): 281–292.

Castro-Martínez C, Beltrán-Arredondo LI, Ortiz-Ojeda JC. 2012. Producción de biodiesel y bioetanol: ¿Una alternativa sustentable a la crisis energética? Ra Ximhai 8 (3): 93–100.

Cadeza-Espinoza M, Brambila-Paz JJ, Chalita-Tovar LE, González-Estrada A. 2017. Evaluación financiera con la metodología de opciones reales de una inversión para producir quitosano con base en desperdicio de camarón. Agricultura, Sociedad y Desarrollo 14 (4): 533–545. https://doi.org/10.22231/asyd.v14i4.694

Cisneros-López MA, García-Salazar JA, Mora-Flores JS, Martínez-Damián MÁ, García-Sánchez RC, Valdez-Lazalde JR, Portillo-Vásquez M. 2020. Evaluación económica con opciones reales: biorrefinería de bioetanol de segunda generación en Veracruz, México. Agricultura, Sociedad y Desarrollo 17 (3): 397–413. https://doi.org/10.22231/asyd.v17i3.1363

CRT (Consejo Regulador de Tequila). 2022. Información estadística. Consejo Regulador de Tequila. Zapopan, México. https://www.crt.org.mx/EstadisticasCRTweb/ (Retrieved: January 2022).

CRT (Consejo Regulador de Tequila). 2019. Manual del técnico tequilero. Consejo Regulador de Tequila. Zapopan, México. https://www.crt.org.mx/images/Documentos/Manual_Tecnico_Tequilero/ManualTecnicoTequilero%20-ImpresionAlta.pdf (Retrieved: April 2022).

Espinoza-Escalante FM, Pelayo-Ortíz C, Navarro-Corona J, González-García Y, Bories A, Gutiérrez-Pulido H. 2009. Anaerobic digestion of the vinasses from the fermentation of *Agave tequilana* Weber to tequila: The effect of pH, temperature and hydraulic retention time on the production of hydrogen and methane. Biomass and Bioenergy 33 (1): 14–20. https://doi.org/10.1016/j.biombioe.2008.04.006

González-Rodríguez S, González-Curbelo G, González-Silva G, Árias-Lafargue T. 2020. Aprovechamiento de la potencialidad de la vinaza para la producción de biogás como energía renovable. Tecnología Química 40 (2): 269–287.

López-Velarde SM, Ventura-Ramos EJ, Rodríguez-Morales JA, Hensel O. 2019. Inoculum adaptation for the anaerobic digestion of mezcal vinasses. Revista Internacional de Contaminación Ambiental 35 (2): 447–458. https://doi.org/10.20937/rica.2019.35.02.15

Lorenzo-Acosta Y, Doménech-López F, Eng-Sánchez F, Almazán-del Olmo O, Chanfón-Curbelo JM. 2015. Tratamiento industrial de vinazas de destilerías en reactores UASB. Tecnología Química 35 (1): 108–123.

Mascareñas-Pérez JM, Lamothe-Fernández P, López-Lubián FJ, Luna-Butz W. 2004. Opciones reales y valoración de activos: Como medir la flexibilidad operativa en la empresa. Pretince Hall: Madrid, España: 238 p.

Ortíz-Rivera MI, Brambila-Paz JJ, Barrera-Islas D, Arjona-Suárez EJ, Torres-Hernández G, López-Reyna MC, Hernández-Martínez J. 2020. Opciones técnicas y económicas para mejorar el ingreso de los productores de durazno [*Prunus persica* (L.) Batsch] en el Estado de México. Agrociencia 54 (2): 279–293.

Pérez-Cerecedo V, Brambila-Paz JJ, Matus-Gardea JA, Barrera-Islas D, González-Estrada A, Portillo-Vásquez M. 2020. Precios, costos y la opción real de expandir la unidad de producción de huevo comercial en México. Agrociencia 54 (4): 589–600. https://doi.org/10.47163/agrociencia.v54i4.2052

PEMEX (Petróleos Mexicanos). 2022. Estadísticas petroleras. Precio al público de productos petrolíferos. Petróleos Mexicanos. Ciudad de México, México. https://www.pemex.com/ri/Publicaciones/Indicadores%20Petroleros/epublico_esp.pdf (Retrieved: December 2021).

Rodríguez-Hernández R, Barrios-Ayala A, Flores-López HE, Sánchez-Vásquez V, Ariza-Flores R. 2016. Factibilidad económica de la producción de bioetanol con tres especies de *Agave* spp. en regiones productoras de México. Revista Mexicana de Ciencias Agrícolas 7 (6): 1439–1453. https://doi.org/10.29312/remexca.v7i6.205

Santiago-Santiago AK, Arana-Coronado OA, Brambila-Paz JJ, Matus-Gardea JA, Sosa-Montes M. 2020. Evaluación financiera con metodología de opciones reales de inversión para producción y venta de café orgánico. Revista Mexicana de Ciencias Agrícolas 11 (3): 493–505. https://doi.org/10.29312/remexca.v11i3.1877

SENER (Secretaría de Energía de México). 2018. Estadísticas energéticas nacionales. Sistema de Información Energética. Secretaría de Energía de México. Ciudad de México, México. https://sie.energia.gob.mx/bdiController.do?action=cuadro&subAction=applyOptions (Retrieved: December 2021).

Valencia-Sandoval K, Brambila-Paz JJ, Mora-Flores JS. 2010. Evaluación del nopal verdura como alimento funcional mediante opciones reales. Agrociencia 44 (8): 955–963.

Valencia-Sandoval K, Zetina-Espinosa AM. 2016. Evaluación de un proyecto de inversión usando opciones reales para diferenciar el aguacate. Estudios Sociales 24 (47): 232–248.

Vargas-Corredor YA, Pérez-Pérez LI. 2018. Aprovechamiento de residuos agroindustriales en el mejoramiento de la calidad del ambiente. Revista Facultad de Ciencias Básicas 14 (1): 59–72. https://doi.org/10.18359/rfcb.3108