How to cite: Şahbaz, M. & E. Sulukan, 2021. Modeling biomass-based biofuel production and developing a reference energy system for the agricultural sector in Turkey, Ege Univ. Ziraat Fak. Derg., 58 (2):171-180, https://doi.org/10.20289/zfdergi.731470

Research Article
(Araştırma Makalesi)

Ege Üniv. Ziraat Fak. Derg., 2021, 58 (2):171-180
https://doi.org/10.20289/zfdergi.731470

Modeling biomass-based biofuel production and developing a reference energy system for the agricultural sector in Turkey

Biyokütle bazlı Biyoyakıt üretiminin modellenmesi ve Türkiye'de tarım sektörü için referans enerji sisteminin geliştirilmesi

Mehmet ŞAHBAZ[1]

Egemen SULUKAN[2]

[1] Karamanoğlu Mehmetbey University, Engineering Faculty, Mechanical Engineering Department, Karaman/Turkey

[2] National Defense University, Turkish Naval Academy, Mechanical Engineering Department, Tuzla-İstanbul/Turkey

* Corresponding author: mehmetsahbaz@kmu.edu.tr

Received (Alınış): **03.05.2020** **Accepted (**Kabul Tarihi): **02.07.2020**

ABSTRACT

Objective: In this study, a reference energy system was developed, and biomass-based biofuel production was modeled for the agricultural sector in Turkey. This was aimed at supplying the entire energy requirement of the agricultural sector using agricultural biomass.

Material and Methods: In the generated model, domestically produced sugar beet, and canola plants were selected as the energy-producing resources. A market allocation model was generated by interfacing the ANSWER software with all of the relevant import and export components.

Results: The reference energy system was developed in six columns, including energy resources and demands. As a result of the use of domestic resources, the dependence on energy to foreign countries will be reduced and a new source of employment will be generated in this sector. Furthermore, the production and consumption of biofuels are more appropriate both in terms of cost and in terms of greenhouse gas emissions than fossil fuels.

Conclusion: The energy demand for the entire agricultural sector is met by the energy supplied from domestic bio-sources produced using part of the agricultural land.

Keywords: Biofuel, Energy modelling, MARKAL, RES, Turkey

ÖZ

Amaç: Bu çalışmada Türkiye'nin tarım sektörü için biyokütle bazlı biyoyakıt üretimi modellenmiş ve referans enerji sistemi geliştirilmiştir. Böylece, tarımsal biyokütle kullanılarak tarım sektörünün tüm enerji gereksiniminin karşılanması amaçlanmıştır.

Material ve Yöntem: Geliştirilen modelde, yurt içinde üretilen şeker pancarı ve kanola bitkileri enerji temin edilecek biyokaynaklar olarak belirlenmiştir. Pazar tahsisi modeli ise, ANSWER yazılımı aracılığıyla tüm girdi ve çıktıların birleştirilmesiyle oluşturulmuştur.

Araştırma Bulguları: Referans enerji sistemi, enerji kaynakları ve talepler de dâhil olmak üzere altı sütun halinde geliştirildi. Yerli kaynakların kullanımı sonucu enerjide dışa bağımlılık azaltılacak ve bu sektörde yeni bir istihdam kaynağı oluşturulacaktır. Ayrıca, biyoyakıtların üretimi ve tüketimi, fosil yakıtlara kıyasla hem maliyet açısından hem de sera gazı salınımı açısından daha uygundur.

Sonuç: Tarım arazisinin bir kısmı kullanılarak üretilen yerli biyo-kaynaklardan sağlanan enerji ile tüm tarım sektörü için gerekli enerji talepleri karşılanmaktadır.

Anahtar kelimeler: Biyoyakıt, Enerji modelleme, MARKAL, RES, Türkiye

INTRODUCTION

The search for alternative energy sources and the efficient utilization of energy is gaining importance with the gradual depletion of fossil fuel reserves. When the environmental impacts are also considered, renewable energy sources are preferred among other alternatives. Apart from solar and wind energy, biofuel production from biomass is seen as an important work area in terms of the relatively low costs and low greenhouse gas emissions. Biofuel production from domestic biomass also reduces Turkey's foreign energy dependency while contributing to agricultural development (Türkekul, 2007). Biofuel usage instead of fossil fuels brings a partial solution to global warming and the depletion of energy sources as the two most essential priorities in international environmental policy. A full replacement of fossil fuels is not currently possible, as the availability of arable land limits production. However, using biofuels at a certain percentage as an additive to fossil fuels should allow reductions in the consumption of fossil fuels and the emission of greenhouse gases (Halleux et al., 2008). Since 2013, a directive published by the Turkish government imposes a minimum of 2% addition of biofuel to the fuels used for road transport consumption. Following this, the percentage was extended to 3% in 2014. Despite the advantages mentioned above of biofuel, its production from biomass can cause various problems in supplying essential agricultural products to the domestic market. For example, based on the legal obligation for a 2% addition of biofuel to fuels, 52000 m^3 of bioethanol is required. To produce this quantity of biofuel, 612000 tons of sugar beets must be processed, while the production of 1 kg of biodiesel, 2.2 kilograms of canola is consumed in the conversion process. Under these circumstances, the detection of raw material and the quantity of produced biofuel and obtained energy stand out as being significant issues in this sector. Developing a reference energy system (RES) and modeling the production of biofuel from biomass is seen as a very useful method for the agricultural sector to visualize agriculture-based energy subsectors and to identify the major components and relevant dynamics from an "energy system analysis" point of view (Karatas et al., 2018; Sulukan et al., 2017a, 2017b).

From this perspective, an enhanced RES was developed specifically for the agricultural sector; domestic sugar beets and canola were specified as the main inputs to biofuel production, considering the total energy needed for agricultural demands. Then, a market allocation (MARKAL) energy–economy–ecology integrated model was generated, which included agricultural irrigation and all the country's agricultural demand for biofuels: biodiesel production from canola and bioethanol from sugar beets.

The MARKAL model generator is currently being developed by the Energy Technology System Analysis Programme (ETSAP), which is already an ongoing multinational program under the International Energy Agency (IEA) (Remme, 2021). The model is also used for scenario analyses in World Energy Outlook reports, which are annually published by the IEA. The MARKAL model of energy balance has been generated for entire countries and specific regions of a country. Tsai and Chang used MARKAL modeling for the reduction of greenhouse gas emissions in Taiwan through nine long-term pathways to the year 2050 (Tsai & Chang, 2015). Spearrin and Triolo generated a MARKAL model for natural gas-based transportation in the United States (Spearrin & Triolo, 2014). It was aimed at the utilization of natural gas as fuel in light- and heavy-duty vehicles instead of oil; an economic evaluation and policy implications of the topic were scripted over a 40-year time horizon based on MARKAL. Ma *et al.* developed a MARKAL model to show the impacts of coal use as an energy supplier on Shanghai's energy and environment (Ma et al., 2015). Hou *et al.* modeled the urban energy system of China using MARKAL to decrease domestic energy consumption (Hou et al., 2010).

In this study, the model consisted of six columns in which domestic canola and sugar beets were used as resources, and biomass-based power plants and biofuel production processes were specified in the system as the main conversion and process technologies. Electricity, biodiesel, bioethanol, bio-hydrogen, biogas, and glycerin were also specified in the model as final energy carriers. Meanwhile, electricity and biodiesel-consuming irrigation pumps, tractors, and agricultural transporters were identified as demand technologies. The generated energy met the main demands of agricultural irrigation, whereas land preparation, agricultural transportation, agricultural fertilizers, agricultural chemicals, and liquid carbon dioxide represented other products of the system and other demands in this area.

From the modeled energy balance system, it was intended that all agricultural energy requirements would be supplied from biomass-based agrarian products. Most of the energy consumption in agriculture can be categorized as agrarian irrigation, land preparation, transportation, fertilizers, or pesticides. The total energy requirement for these categories was produced from sugar beets and canola using energy conversion and other process technologies. Finally, a comparison was made between fossil fuels and biofuel utilization to meet agricultural energy demands in terms of their emissions and energy-saving levels (Çoşar & Engindeniz, 2011).

MATERIAL and METHODS

Many kinds of plants are available to produce biofuel and sugar-based plants are used in the production of bioethanol, whereas oil-based plants are used in the production of biodiesel. The most preferred plant types for bioethanol production are sugar cane, sugar beets, potatoes, cassava, maize, rice, barley, wheat, sweet sorghum, and bagasse (Balat & Öz, 2008). In biodiesel production (Özçelik, 2017), the generally preferred plants are rapeseed (canola), soybean, oil palm, sunflower, peanut, safflower, cotton, and avocado. Among these raw materials, sugar beets and canola are widely grown in different regions of Turkey and are used in biofuel production (Eryilmaz et al., 2016). Therefore, these two plants were identified as significant energy resources in the agricultural sector from which to obtain electricity and biodiesel/bioethanol-based fuel. In this way, an autonomous RES was designed. This state was desired for the agriculture sector to supply its total energy demand from domestic production, using both of these plants as resources. In order to make the model more realistic, it was deemed appropriate to supply all energy sources from raw materials rather than bio-waste. Bioethanol production from beet waste or biodiesel production from canola waste or waste oil was not included in the model. Because the efficiency of the energy obtained from waste materials will vary according to the region where the product is grown. Together with this, the raw materials sugar beet and canola are referred to below as agricultural waste (AGRW) in the RES model and analysis.

To oversee the general situation of the agricultural sectoral activities, a detailed energy network scheme, namely the reference energy system, has been developed. RES contains the current and the future perspectives of the agricultural sector in terms of energy carriers and related technologies. An energy–economy–ecology balance system was modeled using the MARKAL-ANSWER software, which has various applications in the literature.

ANSWER is a user-friendly Windows interface, specially developed for working with the MARKAL energy system model. The MARKAL model generators were developed by the Energy Technology Systems Analysis Program (ETSAP) of the IEA.

The ANSWER interface allows the energy modeler to enter, edit, and browse the data to execute a model run and obtain the relevant results within the optimized energy system architecture. The phases of ANSWER operation can be summarized as follows:

- Initially, a database is constructed.
- Then the data is entered into this database through the ANSWER interface.
- A reference energy system is obtained by identifying the interrelations in the focused energy system, and an energy network flow chart is handled.
- The technology sets utilized in energy production and consumption are entered into this energy system model, including the user-defined constraints.

In this energy modeling study, the general energy balance data for the year 2010 were used as reference values of the Turkish National Committee. First, the RES was developed based on six main columns: resources, primary energy carriers, conversion and process technologies, final energy carriers, end-use technologies, and demand. The sub-headings of these columns were determined by the modeler and added under the six major column headings of the RES. Then, the relevant connections were made between sub-headings using links, and the main framework of the RES was generated.

As a second step, the generated RES scheme was regenerated in the ANSWER software (as shown in Figure 1), and the required data was entered into a model obtained from official statistics (Figure 2).

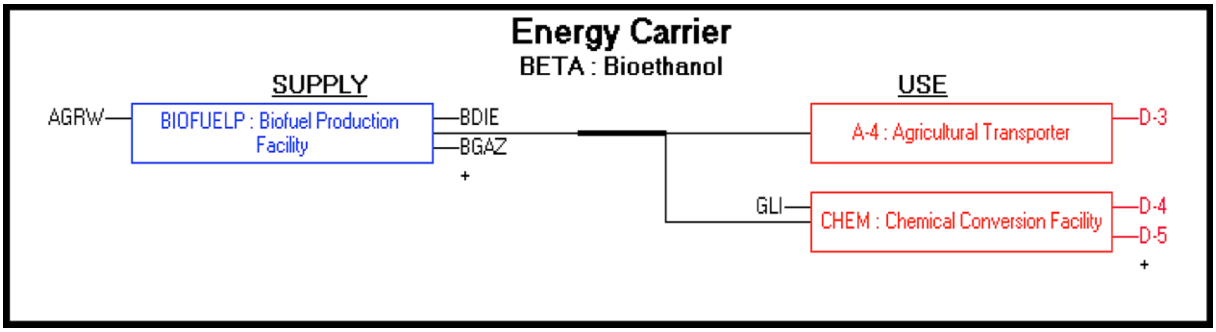
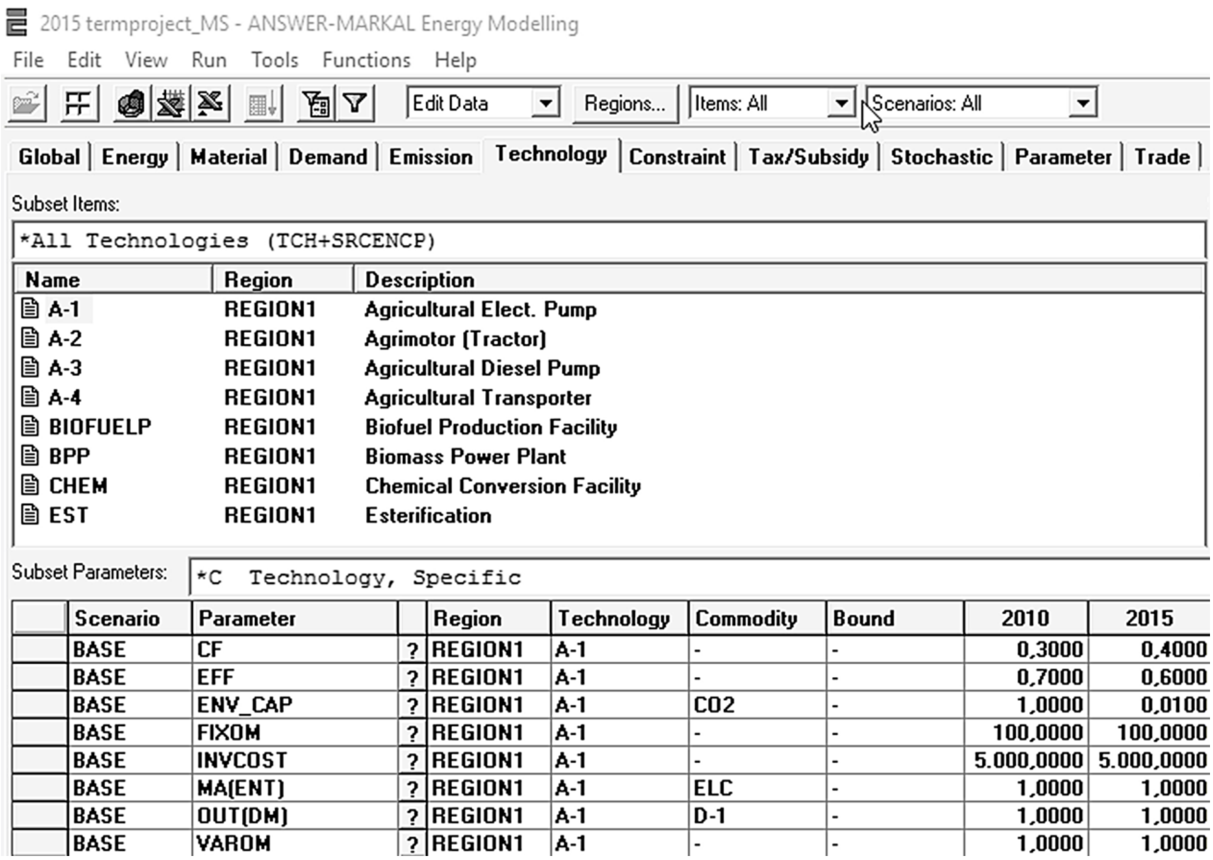


Figure 1. The bioethanol-centered part of the RES generated by the ANSWER software.

Şekil 1. *ANSWER yazılımı ile üretilen RES'in biyoetanol merkezi parçası.*

As an example, the process of bioethanol production from agricultural waste (AGRW) in a biofuel production facility and the produced bioethanol were linked to agrarian transportation and the chemical conversion facility as end-use technologies.



Name	Region	Description
A-1	REGION1	Agricultural Elect. Pump
A-2	REGION1	Agrimotor (Tractor)
A-3	REGION1	Agricultural Diesel Pump
A-4	REGION1	Agricultural Transporter
BIOFUELP	REGION1	Biofuel Production Facility
BPP	REGION1	Biomass Power Plant
CHEM	REGION1	Chemical Conversion Facility
EST	REGION1	Esterification

	Scenario	Parameter		Region	Technology	Commodity	Bound	2010	2015
	BASE	CF	?	REGION1	A-1	-	-	0,3000	0,4000
	BASE	EFF	?	REGION1	A-1	-	-	0,7000	0,6000
	BASE	ENV_CAP	?	REGION1	A-1	CO2	-	1,0000	0,0100
	BASE	FIXOM	?	REGION1	A-1	-	-	100,0000	100,0000
	BASE	INVCOST	?	REGION1	A-1	-	-	5.000,0000	5.000,0000
	BASE	MA(ENT)	?	REGION1	A-1	ELC	-	1,0000	1,0000
	BASE	OUT(DM)	?	REGION1	A-1	D-1	-	1,0000	1,0000
	BASE	VAROM	?	REGION1	A-1	-	-	1,0000	1,0000

Figure 2. ANSWER software interface showing all technologies and data of the model.

Şekil 2. *ANSWER yazılımının ara yüzü modelin tüm teknolojilerini ve verilerini gösteriyor.*

This case gave the required final energy related to the demands (D3–D5). As shown above, in Figure 1, part of the RES was explicitly focused on the bioethanol production-consumption phases and illustrated the bioethanol-related path in the energy system. Figure 2 shows the technologies screen with the data entered into the software.

Reference energy system

Figure 3 schematically shows the energy generation from resources, energy carriers and technologies, and agricultural energy demands supplied in this model. This main body is known as the RES (described previously).

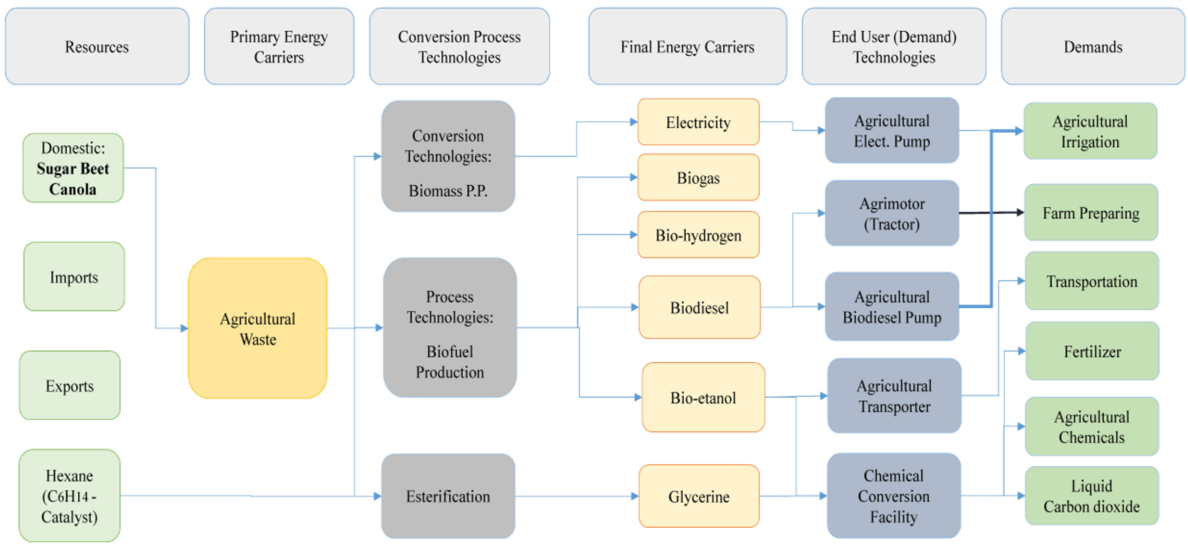


Figure 3. Reference energy system for biomass-based biofuel production.

Şekil 3. *Biyokütle bazlı biyoyakıt üretimi için referans enerji sistemi.*

Resources

Generally, the RES contained three types of resources, which are domestic, imports, and exports; stocks can also be grouped under this classification. The RES of the Turkish agricultural sector included only domestic resources as sugar beets, canola, and hexane. This structure could be altered depending on variations in fuels or technologies. The specified resources are described below.

Sugar beets: A sugar beet is a plant that consists of a root and long, green leaves. High concentrations of sucrose, formed by photosynthesis in the leaves, are stored in the root. A sugar beetroot has almost 1 kg of mass, which is composed of 20% sugar, 75% water, and 5% pulp. Sugar beets are generally grown for sugar production, although in recent years they have also been used in bioethanol production.

Canola: Canola, also known as rapeseed, is used to in the production of canola oil from its seed. It is also used as a biomass source in biodiesel production (Dupont et al., 1989).

Hexane (C_6H_{14}) catalyst: Hexane is a straight-chain alkane and is the most important component of gasoline. It is odorless, colorless and has a liquid form at room temperature. It is widely used in laboratories as an oil solvent and the industry as an organic solvent.

Imports: No imports were identified in this reference energy system because agricultural product importation is still not more cost-effective than fossil fuel importation.

Exports: Currently, there is no exportation from Turkey of biofuel or any other type of agricultural raw material for biofuel production. However, biofuel or the related raw materials could be exported in the future based on the country's high potential for agricultural production.

Primary energy carriers

Agricultural waste: The primary energy carriers were classified under one title as 'agricultural waste' to simplify the modeling process. These included sugar beet and canola wastes, which are used in biofuel and electricity production. These products can be produced alternatively from various raw materials.

Conversion process technologies

Conversion technologies (Biomass power plant): Biomass power plants are used to generate electricity from biomass; agricultural wastes were used as biomass in electricity generation in our RES. In this model, the electricity generated from biomass-based power plants was used mostly in electrical pumps for agricultural irrigation purposes.

Process technologies (Biofuel production): Biofuel production is process technology, and after some processing biodiesel, bioethanol, biogas, and bio-hydrogen are produced as end products. Biodiesel is generally produced from the plants' oils of canola, corn, and cotton. Also, bioethanol is produced, mostly from the syrup of sugar beets and sugar cane by following some processes, as seen in Figure 4 (Hansdah & Murugan, 2016). The hexane catalyst is added as a solvent to the raw material when producing biodiesel in the biofuel production process.

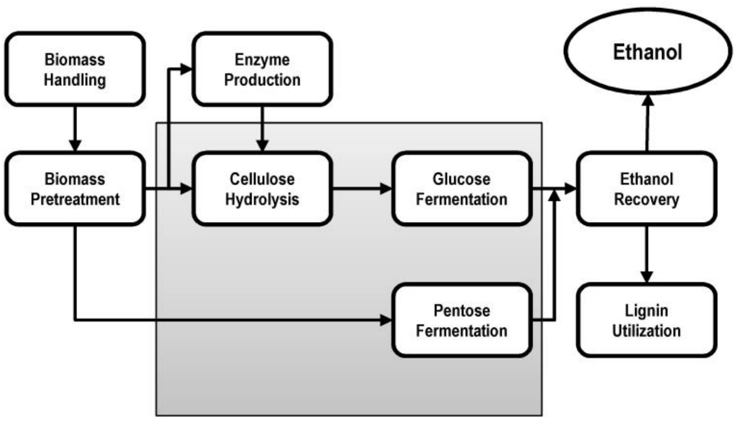


Figure 4. Bioethanol production process.

Şekil 4. *Biyoetanol üretim süreci.*

Esterification: Glycerin can be obtained through an esterification process by adding hexane catalyst to biofuel raw material. Many types of fertilizers and chemicals can be produced from glycerin or the esterification process.

Final energy carriers

In the generated reference system, six types of final energy carriers are used. Electricity, biodiesel, and bioethanol are used for demands, and others can be used in energy production. The energy carriers are listed as electricity, biogas, bio-hydrogen, biodiesel, bioethanol, and glycerin.

Electricity is used directly to run electrical pumps for agricultural irrigation. Biodiesel is also used for agricultural irrigation by diesel pumps and tractors. It is also used in tractors for various phases of land preparation. Bioethanol is used for vehicles to carry agricultural materials and products. Glycerin is used to produce fertilizer and agricultural chemicals, such as pesticides used in agricultural spraying.

End-use (demand) technologies

All kinds of fuels produced by conversion and process technologies are utilized in end-user (demand) technologies. These technologies provide energy and materials to satisfy various demands in agricultural activities. The identified end-use technologies in the RES were listed as agricultural electrical pumps, agrimotors (tractors), agricultural biodiesel pumps, agricultural transporters, and chemical conversion facilities.

Demands

From the demand side point of view, the primary objective of this study was to construct a supply-demand equilibrium to supply the energy required for agricultural irrigation from agricultural waste. Therefore, the first demand of this RES was determined as agricultural irrigation. Apart from this, the remainder of the produced energy was identified to be utilized in land preparation and transportation. In the RES, the number of by-products was specified to meet other agricultural demands, such as fertilizing, agricultural spraying, and liquid carbon dioxide. The main demands of the RES were agricultural irrigation, land preparation, transportation, fertilizers, agricultural chemicals, and liquid carbon dioxide.

Agricultural irrigation: The surface area of Turkey is 78 million hectares, and its agricultural area is 28 million hectares, which is nearly one-third of the total area of the country. The irrigated area is almost five million hectares (Sayin et al., 2005).

The agricultural sector consumes 3.5% of the total energy, which was 113.9 PJ in 2010. In the same year, the total energy consumption in Turkey was 3255.1 PJ. Agricultural irrigation consumes 1.5% of this total (49.64 PJ). In summary, 19.8 PJ of energy is consumed as electricity, whereas 29.84 PJ of energy is consumed as oil fuel products ("IEA-ETSAP," 2019).

Fertilizer and agricultural chemicals: Some agricultural chemicals and fertilizers can be obtained as by-products of biofuel production, which can be summarized as follows:

- Glycerin and its derivatives
- Vegetable-sourced liquid organic fertilizers containing amino acids
- Liquid organic fertilizers containing zinc (Zn), boron (B), iron (Fe), sulphur trioxide (SO_3) and manganese (Mn)
- Spreaders and binders to increase the efficiency of fertilizers

Liquid carbon dioxide: Liquid carbon dioxide, a waste product of bioethanol production, can be used as a raw material in sugar mills at a very low cost owing to its high productivity and quality in ultra-climate greenhouses.

The liquid carbon dioxide can also be exported and is used in the fizzy beverage industry; grain, fig and pulse storehouses; the freezing of meat, meat products, fish and sea products; the freezing of fruits and vegetables; cooling biscuit dough; dry ice production; plastic industry; sponge and Styrofoam production; iron and steel production; fire extinguishers; and as a cushion in the transfer of hazardous liquids (Yuksel & Ozturk, 2017).

RESULTS

The RES determines the energy flows, respective components, interactions, and reflects the current structure of the agricultural sector in Turkey. Additionally, RES and its database may be enriched by the additional energy carrier and technology options for future analysis requirements. The agricultural sector in Turkey supplies energy mainly by using sugar beets and canola. The primary outcome of this study was the construction of an agricultural sector-focused RES using the MARKAL modeling platform. This analysis has been a breakthrough for the country as the first energy modeling application in the agricultural sector, while no energy system analyses had been conducted so far in this sector. The respective calculations and the developed RES showed that the generated energy is sufficient for the significant aims of agricultural irrigation, and additional energy and materials were also appraised in the same sector.

Energy Production from Bioethanol

One hectare of land produces nearly 50 tons of sugar beets, and 11 tons of sugar beets can produce one ton of bioethanol. In other words, 4.6 tons of bioethanol is produced from a one-hectare field. By using one-tenth of the agricultural area (0.45 million hectares), 2.07 million tons (2836 million liters) of bioethanol can be produced, which would address an energy production requirement of 60.35 PJ/year (Balat et al., 2008; Bayrakci Ozdingis & Kocar, 2018). The specific energy and energy densities of the fuels are given with the chemical formula in Table 1 ("Green Econometrics Analysis," 2008) to make a comparison between them.

Table 1. Specific energy, energy density and CO_2

Çizelge 1. *Özgül enerji, enerji yoğunluğu ve CO_2*

Fuel	Specific Energy kJ /g	Energy Density kWh/gal	Chemical Formula
Propane	50.4	28.8	C_3H_8
Ethanol	29.7	24.7	C_2H_5OH
Gasoline	46.5	36.6	C_7H_{16}
Diesel	45.8	40.6	$C_{12}H_{26}$
Biodiesel	39.6	35.0	$C_{18}H_32O_2$
Methane	55.8	27.0	CH_4
Oil	47.9	40.5	$C_{14}H_{30}$
Wood	14.9	11.3	approx. weight
Coal	30.2	22.9	approx. weight
Hydrogen	141.9	10.1	H_2

Energy Production from Biodiesel

Canola is harvested at a rate of 2.5 tons from a one-hectare field, and 0.33 tons of canola oil is produced from one ton of canola. Furthermore, one ton of biodiesel is produced from one ton of canola oil (0.83 tons of biodiesel). As a result, 830000 tons of biodiesel can be produced by using one-fifth of the irrigated area of Turkey, which is one million hectares. Finally, 830000 tons of biodiesel equals one million liters biodiesel, which addresses the requirement of 33.21 PJ/year (Eryilmaz et al., 2016). In order to present and to compare the emission of the fuels, Table 2 (Halleux et al., 2008) is given below. Therefore, biofuels are can be accepted as more environmentally friendly than their fossil-derived counterparts.

Table 2. Energy consumption and exhaust emissions of vehicles

Çizelge2. Araçların Enerji tüketimi ve egzoz emisyonları

	Petrol	Diesel	Bioethanol	Biodiesel (RME)
Consumption (MJ/100 km)	223.5	183.1	223.5	183.1
CO_2 (fossil) (kg/100 km)	16.6	13.4	0	0.74
CH_4 (mg/100 km)	2.4	7.6	2.4	7.6
N_2O (mg/100 km)	0.129	0.0645	0.129	0.0645
NO_X (mg/100 km)	10.2	25.6	6.35	28.2
Particulates (mg/100 km)	0.5	3.56	0.5	1.89
NMVOC (mg/100 km)	2.53	9.59	6.36	3.17

CONCLUSION

Firstly, the development of a comprehensive energy-technology database, namely the RES is the main output of this analysis. The RES may be altered to contain future energy carriers (i.e.: hydrogen) or respective technologies to be utilized in the Turkish agricultural sector. In addition to these issues, it is seen that most of the energy demand in the agricultural sector is for irrigation. By this study, a total of required energy (93.56 PJ) can be generated by harvesting sugar beets and canola from an area of 1.45 million hectares. Also, the other demands such as land preparation, agricultural transportation, fertilizing and agricultural spraying can be supplied entirely from this energy through biofuel utilization.

1. This production capacity also creates employment in the agricultural sector and gives higher importance to excess production and plant wastes.
2. Also, biofuel-based fuels result in lower greenhouse gas emissions than fossil fuels: one liter of bioethanol prevents the release of 2.9 kg of carbon dioxide from the time a sugar beet is planted to its use as energy.
3. Sugar beets produce three times more oxygen than other plants in the same area, and when E10 fuel is used in vehicles instead of gasoline, the greenhouse gas emissions are decreased by nearly 3–4%, whereas using E85 (85% bioethanol + 15% gasoline) instead of 100% gasoline decreases emissions by up to 75% (Bayrakci Ozdingis & Kocar, 2018).

ACKNOWLEDGMENTS

The authors sincerely thank the Editor for considering the paper for publication in this reputed journal. The authors also sincerely thank the reviewers for their valuable suggestions for improving the manuscript.

REFERENCES

Balat, M., H. Balat, & C. Öz, 2008. Progress in bioethanol processing. Progress in Energy and Combustion Science, *34*(5): 551–573. https://doi.org/10.1016/j.pecs.2007.11.001

Bayrakci Ozdingis, A. G., & G. Kocar, 2018. Current and future aspects of bioethanol production and utilization in Turkey. Renewable and Sustainable Energy Reviews, 81: 2196–2203. https://doi.org/10.1016/j.rser.2017.06.031

Çoşar, G. Ö., & S. Engindeniz, 2011. Tarım Arazilerinin Değerlemesinde Coğrafi Bilgi Sisteminden Yararlanma Olanakları. Ege Üniversitesi Ziraat Fakültesi Dergisi, 48(3): 283–290. https://doi.org/10.20289/eüzfd.37475

Dupont, J., P. J. White, K. M. Johnston, D. H. Alexander Heggtveit, B. E. McDonald, S. M. Grundy, & A. Bonanome, 1989. Food Safety and Health Effects of Canola Oil. Journal of the American College of Nutrition, 8(5): 360–375. https://doi.org/10.1080/07315724.1989.10720311

Eryilmaz, T., M. K. Yesilyurt, C. Cesur, & O. Gokdogan, 2016. Biodiesel production potential from oil seeds in Turkey. Renewable and Sustainable Energy Reviews, 58: 842-851. https://doi.org/10.1016/j.rser.2015.12.172

Green Econometrics Analysis. 2008. Economic analysis and analytics for sustainability and process improvement. (Web page; http://greenecon.net/page/3) (Data accessed: June 2021)

Halleux, H., S. Lassaux, R. Renzoni, & A. Germain, 2008. Comparative life cycle assessment of two biofuels: Ethanol from sugar beet and rapeseed methyl ester. International Journal of Life Cycle Assessment, 13(3): 184–190. https://doi.org/10.1065/lca2008.03.382

Hansdah, D. & S. Murugan, 2016. Comparative studies of a bioethanol fuelled DI diesel engine with a cetane improver. International Journal of Oil, Gas and Coal Technology, 11(4): 429–450. https://doi.org/10.1504/IJOGCT.2016.075088

Hou, W., J. Sun, L. Fu, & L. Liu, 2010. "Urban energy system analysis by markal model in China, 211–217". ASME International Mechanical Engineering Congress and Exposition (IMECE), Book of Proceedings, British Columbia, Canada, Vol: 5, 211 pp. https://doi.org/10.1115/IMECE2010-37417

IEA-ETSAP, 2021. The Energy Technology Systems Analysis Program, International Energy Agency, (Web page; https://iea-etsap.org/) (Data accessed: June 2021)

Karatas, M., E. Sulukan, & I. Karacan, 2018. Assessment of Turkey's energy management performance via a hybrid multi-criteria decision-making methodology. Energy, 153(15): 890-912. https://doi.org/10.1016/j.energy.2018.04.051

Ma, X., M. Chai, L. Luo, Y. Luo, W. He, & G. Li, 2015. An assessment on Shanghai's energy and environment impacts of using MARKAL model. Journal of Renewable and Sustainable Energy, 7(1):1-14 https://doi.org/10.1063/1.4905468

Özçelik, A. E. 2017. Common-Rail Dizel Motorda Aspir Biyodizeli ile Eurodizel Karışımlarının Motor Performansı ve Emisyonlarına Etkisinin İncelenmesi. Ege Üniversitesi Ziraat Fakültesi Dergisi, 54(1): 9–16. https://doi.org/10.20289/zfdergi.297905

Remme, U. 2012. "Capacity Building through Energy Modelling and Systems Analysis", Developments in Energy Education: Reducing Boundaries, Workshop (9-12 May 2012), Copenhagen, Denmark

Sayin, C., M. Nisa Mencet & B. Ozkan, 2005. Assessing of energy policies based on Turkish agriculture: Current status and some implications. Energy Policy, 33(18): 2361–2373. https://doi.org/10.1016/j.enpol.2004.05.005

Spearrin, R. M. & R. Triolo, 2014. Natural gas-based transportation in the USA: Economic evaluation and policy implications based on MARKAL modeling. International Journal of Energy Research, 38(14): 1879–1888. https://doi.org/10.1002/er.3199

Sulukan, E., M. Sağlam & T. S. Uyar, 2017a. "Energy–Economy–Ecology–Engineering (4E) Integrated Approach for GHG Inventories". In: Carbon Management, Technologies, and Trends in Mediterranean Ecosystems. (Eds. S. Erşahin, S. Kapur, E. Akça, A. Namlı & H. Erdoğan) Vol: 15, Springer, Cham. 88 pp. https://doi.org/10.1007/978-3-319-45035-3_7

Sulukan, E., M. Sağlam & T. S. Uyar, 2017b. "Technical Efficiency Improvement Scenario Analysis for Conversion Technologies in Turkey". In: Towards 100% Renewable Energy. Springer Proceedings in Energy, (Eds. Uyar T), Springer, Cham. 129 pp, https://doi.org/10.1007/978-3-319-45659-1_12

Tsai, M. S. & S. L. Chang, 2015. Taiwan's 2050 low carbon development roadmap: An evaluation with the MARKAL model. Renewable and Sustainable Energy Reviews, 49: 178–191. https://doi.org/10.1016/j.rser.2015.04.153

Türkekul, B. 2007. Türkiye'de Enflasyon-Büyüme İlişkisi: Tarım Sektörü İtibariyle Ekonometrik Bir Analiz. Ege Üniversitesi Ziraat Fakültesi Dergisi, 44(1): 163–175.

Yuksel, Y. E. & M. Ozturk, 2017. Energy and exergy analysis of renewable energy sources-based integrated system for multi-generation application. International Journal of Exergy, 22(3): 250–278. https://doi.org/10.1504/IJEX.2017.083170