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RESEARCH

Energy Use and Emission Efficiency in White Cherry Production: Evidence from Türkiye

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Abstract

White cherry fruit is grown primarily in Konya Province's Ereğli District. The purpose of this study was to investigate the energy usage, energy efficiency and greenhouse gases (GHGs) produced by white cherry fruit in Konya's Ereğli District. The data utilized within this study were collected through surveys with 30 growers during the 2025 production season; therefore, the survey data were analyzed in terms of the energy equivalencies and carbon emission factors of the inputs involved in the white cherry fruit production process. Energy usage efficiency was determined to be 4.01 MJ/ha and 45,618.31 MJ/ha. Additionally, the energy productivity, specific energy, and net energy usage per hectare were determined to be 1.37 kg/MJ, 0.80 MJ/kg, and 45,427.04 MJ/ha, respectively. The largest proportions of energy usage were in the form of chemical fertilizers at 37.73%, and electrical energy at 34.87%. Thus, the energy usage due to chemical fertilizers and electrical energy accounted for approximately two-thirds of the total energy utilization. The total GHG emissions associated with white cherry fruit production were 1185.74 kg CO2-eq/ha. A product-based GHG emission value of 0.06 kg CO2-eq/kg was also estimated. In addition, it was estimated that the majority (>80%) of the electrical energy consumed was from non-renewable energy sources. Approximately 84.6% of the energy usage comprised non-renewable energy sources, while 15.4% comprised renewable energy sources. These results indicate a positive energy balance in white cherry fruit production; however, an increase in renewable energy usage would result in sustainable development in this area. In order to decrease both energy expenses and the carbon footprint of the white cherry fruit production system, growers could utilize energy efficient irrigation systems and solar power. The usage of nitrogen fertilizer should be optimized to minimize the carbon footprint.

Keywords Agricultural sustainability · Fruit production systems · Energy performance indicators · Greenhouse gas emissions · Sustainable agriculture · Türkiye

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Introduction

Due to increasing global warming and resource depletion, agriculture is now one of the most important sectors in sustainable development studies and policies. The United Nations (UN) (United Nations 2023) and the Food and Agriculture Organization of the United Nations (FAO 2022) state that agriculture is responsible for approximately 20% of greenhouse gas (GHG) emissions, making managing energy use and reducing carbon emissions in agriculture a key area of concern. Agriculture provides food supplies, but because the processes involved in agriculture consume so much energy, it puts extreme pressure on the environment. Statistics from the Intergovernmental Panel on Climate Change (IPCC 2021) indicate that irrigation energy and nitrogen fertilizer use are the most significant factors contributing to the environmental burden of agricultural production. Therefore, it is necessary to measure the energy efficiency of production systems and to design measures and policies to combat carbon emissions, which are an inevitable byproduct of agricultural production. Turkey has a high level of raisin production and climatic variation, and therefore has very high potential for cherry cultivation. Thanks to white cherry production, Turkey not only has a significant source of income from foreign sales but also is a very popular fruit in the country. However, recent increases in energy prices and changes in climatic conditions in the production areas of white cherry cultivation have caused some problems regarding the sustainability of this particular variety in Türkiye. Energy and carbon analysis are the most important factors in terms of environmental factors of production systems. It also assists in decision-making processes regarding improving production efficiency (Zhang et al. 2021). In the last decade, many studies have been reported on the relationship between energy use and GHG emissions in agriculture. Many of these studies are quantitative studies on the relationship between energy inputs and carbon emissions in a production system. In this context, Say et al. (2024) stated that energy efficiency is one of the production factors that has a significant impact on the environmental performance of fruit production; Ozalp et al. (2018) reported that approximately two-thirds of the energy required for a number of incentive production systems in Türkiye consists of electrical energy and fertilizer; Khoshnevisan et al. (2014) showed that nitrogen fertilizers and irrigation are the main energy inputs leading to carbon emissions in orchards in Iran; Houshyar et al. (2015), using life cycle assessment tools as applicable, showed that there is a direct link between the energy cost of apple production and the extent of carbon emissions. In addition to these studies, studies on carbon emissions and energy use have been conducted for orange (Ağızan et al. 2025; Saltuk et al. 2022), walnut (Çelik et al. 2024; Candemir et al. 2024), winegrapes (Güner and Candemir 2026), grape (Şimşek et al. 2022), sunflower (Baran et al. 2016), mandarin, (Candemir et al. 2025a), cotton (Gokdogan et al. 2016), wheat (Candemir 2020), vetch (Kokten et al. 2017), and garlic (Baran et al. 2023). FAO (2021) and IPCC (2021) reports indicate that approximately 20% of agricultural emissions originate from crop production, and therefore, energy management and carbon absorption should be an integral part of production programming. The aim of this study is to provide information on the assessment of energy use, energy efficiency, and carbon emissions in white cherry production in the Ereğli district of Konya province, to provide information on the renewable and non-renewable energy conversion rate of the production system, and to determine the sustainability of production methods. It is hoped that the results of this study will lead to more efficient methods and low-carbon fruit production models in line with the sustainable development goals proposed by the FAO (FAO 2021) in its "sustainable food systems" strategy and the United Nations (Sustainable Development Goal [SDG] 12 and SDG 13).

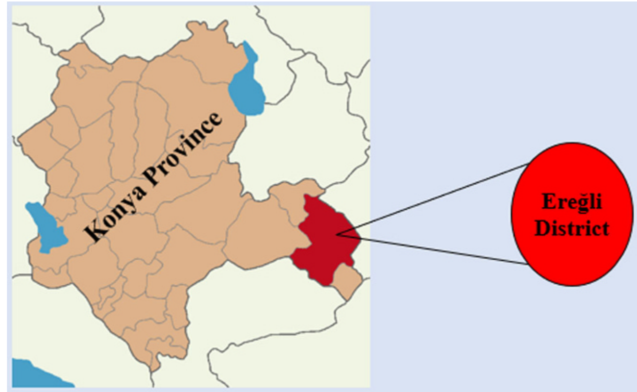

Fig. 1 Research area map

Methodology

The research was conducted in the Ereğli District of the Province of Konya in Türkiye's Central Anatolian Region (Fig. 1). The district is one of the central regions for the production of white cherry in this area of Türkiye due to its climatic conditions, the soil type and the availability of irrigation. The data used in the study were collected by means of a face-to-face survey with the producers of the region during the 2025 production year. The survey questionnaire contains producers' input data, their energy consumption, data about the producers' production practices and yield data.

The sample size was determined by the simple random sampling method suggested by Newbold (1995). In this method, the sample size was found using the following formula:

$$n = \frac{Np\,(1-p)}{(N-1)\,\sigma_{px}^2 + p\,(1-p)}$$

where n = sample size, p = the proportion of individuals with certain character, and q = (1–p) value. If the value of this ratio is not known, the value of p is assumed to be 0.5 to give the maximum sample size. The formula d = (percentage of error × mean), is used for calculating the margin of error, and the t value also is determined according to whether the sample size is over 30 or not, in obtaining the confidence interval. Experimentation with the principles by the means of surveying 30 producers gave satisfactory results. The surveys were made in the villages of Ereğli district where the highest white cherry product is raised.

Table 1 Standard coefficients to compute energy content of outputs and inputs in white cherry production

Inputs	Unit	Energy equivalent (MJ unit^{-1})	References
Labor	H	1.96	Mani et al. (2007); Karaağaç et al. (2011)
Machinery			
Tractor	H	25.4	Singh et al. (2002)
Plough	H	18.7	Singh et al. (2002)
Pesticides			
Insecticides	Kg	278	Khoshroo and Mulwa (2014); Rafiee et al. (2010)
Fungicides	Kg	216	Khoshroo and Mulwa (2014); Rafiee et al. (2010)
Organic fertilizers			
Farmyard manure	Kg	0.30	Singh et al. (2002)
Chemical fertilizers			
Nitrogen	Kg	60.60	Singh et al. (2002); Ozalp et al. (2018)
Phosphorus	Kg	11.10	Mandal et al. (2002); Candemir et al. (2024)
Potassium	Kg	6.70	Mandal et al. (2002)
Others			
Diesel	L	56.31	Singh et al. (2002); Bayramoğlu et al. (2025)
Irrigation water	m^3	0.63	Acaroglu (1998); Azizi and Heidari (2013)
Electricity	kWh	3.60	Ozkan et al. (2004)
Transportation	MJ.t.km	4.5	Fluck and Baird (1982); Kitani (1999)
Output	Unit	Energy equivalent (MJ unit^{-1})	Reference
White Cherry	Kg	2.93	Proebsting (1980); Sarı and Gökdoğan (2024)

Energy inputs used were obtained in the white cherry culture by multiplying the amount of each input used in the production by the energy equivalents of each of such inputs. These, in the method of calculation, were obtained from the standard values given in Table 1. These coefficients were adopted from those recommended by Singh et al. (2002), Mandal et al. (2002) and Ozkan et al. (2004) values. The total energy input was obtained by computing the energy equivalents of those inputs, such as human labor, machinery, fuel, fertilizer, irrigation, water, and electricity, separately. The carbon emissions resulting from the production of white cherries were determined by using those emission coefficients based on energy equivalents. These coefficients are figured in Table 2 and were obtained from the standards given by Lal (2004), Dyer and Desjardins (2006), and Khoshnevisan et al. (2014). Each energy input was multiplied by the coefficient of emission equivalent for such input, thus evaluating together direct (fuel, electricity, water) and also indirect emission (fertilizer, machinery, pesticide). The formulas prepared by Mandal et al. (2002) and Singh et al. (2002) were used in determining the energy use efficiency (EUE). According to this method, EUE, energy

Table 2 Greenhouse gas (GHG) emission coefficients in production

Inputs	Unit	GHG equivalent ($kgCO_{2\text{-}eq}$ unit^{-1})	References
Labor	H	0.7	Houshyar et al. (2015)
Machinery	MJ	0.071	Pishgar-Komleh et al. (2012); Eren et al. (2019b)
Farmyard manure	Ton	0.029	Meisterling et al. (2009)
Insecticide	Kg	6.300	Graefe et al. (2013)
Fungicide	Kg	3.900	Graefe et al. (2013)
Nitrogen	Kg	1.300	Lal (2004); Candemir et al. (2025b)
Phosphorus	Kg	0.200	Lal (2004); Ozalp et al. (2018)
Potassium	Kg	0.200	Taghavifar and Mardani (2015)
Diesel	L	2.760	Dyer and Desjardins (2006); Ozalp et al. (2018)
Electricity	kWh	0.608	Khoshnevisan et al. (2014)
Transportation	Kg	0.150	Meisterling et al. (2009); Eren et al. (2019b)

productivity, specific energy, and net energy were obtained as follows:

$$\text{Energy use efficiency} = \frac{\text{Energy output}\left(\frac{MJ}{ha}\right)}{\text{Energy input}\left(\frac{MJ}{ha}\right)} \quad (1)$$

$$\text{Specific energy} = \frac{\text{Energy input}\left(\frac{MJ}{ha}\right)}{\text{Yield output}\left(\frac{kg}{ha}\right)} \quad (2)$$

$$\text{Energy productivity} = \frac{\text{Yield output}\left(\frac{kg}{ha}\right)}{\text{Energy input}\left(\frac{MJ}{ha}\right)} \quad (3)$$

$$\text{Net energy} = \text{Energy output}\ (MJ\ ha^{-1}) - \text{Energy input}\ (MJ\ ha^{-1}) \quad (4)$$

The GHG emissions ($kgCO_{2\text{-eq}}kg^{-1}$) for producing 1 ha of white cherry were calculated using the method developed by Hughes et al. (2011). The calculation involves finding the sum, denoted by $\sum$, of the product of the application ratio of input i ($unit_{input}ha^{-1}$), denoted by R(i), and the GHG emission coefficient of input i ($kgCO_{2\text{-eq}}unit_{input}^{-1}$), denoted by EF(i). However, an index has been devised to measure the amount of $kgCO_{2\text{-eq}}$ emissions spread per kg yield, using the following formula proposed by Houshyar et al. (2015). In this formula, I_{GHG} represents the GHG ratio and Y refers to the yield in kg per ha (Eren et al. 2019a):

$$GHG_{ha} = \sum_{i=1}^{n} R(i)\, x EF(i) \quad (5)$$

$$I_{GHG} = \frac{GHG_{ha}}{Y} \quad (6)$$

Table 3 Energy use efficiency in white cherry production

Inputs	Unit	Energy equivalent (MJ unit^{-1})	Input used per hectare (unit ha^{-1})	Energy value (MJ ha^{-1})	Ratio (%)
Labor	–	–	32.66	64.02	0.39
Pruning	h	1.96	7.60	14.9	0.09
Soil tillage (2 times)	h	1.96	1.21	2.38	0.01
Fertilizing (chemical and farmyard)	h	1.96	1.94	3.8	0.02
Spraying	h	1.96	2.23	4.38	0.03
Irrigation	h	1.96	1.44	2.83	0.02
Harvesting	h	1.96	16.27	31.89	0.20
Transportation	h	1.96	1.97	3.85	0.02
Machinery	–	–	6.34	152.96	0.94
Tractor	h	25.4	5.13	130.25	0.80
Plough (2 times)	h	18.7	1.21	22.71	0.14
Pesticides	–	–	4.97	1278.73	7.86
Fungicide	kg	216	1.66	358.28	2.20
Insecticide	kg	278	3.31	920.45	5.66
Farmyard Manure	kg	0.3	146.37	43.91	0.27
Chemical fertilizers	–	–	241.00	6139.53	37.73
Nitrogen	kg	60.6	75.03	4546.96	27.94
Phosphorus	kg	11.1	109.23	1212.45	7.45
Potassium	kg	6.7	56.74	380.12	2.34
Diesel	L	56.31	7.81	439.53	2.70
Irrigation water	m3	0.63	3921.63	2470.63	15.18
Electricity	kWh	3.6	1576.36	5674.9	34.87
Transportation	MJ.t.km	4.5	1.97	8.84	0.05
Total Input	–	–	–	16,273.05	100.00
Output	Unit	Energy equivalent (MJ/unit)	Output per hectare (unit ha^{-1})	Energy value (MJ ha^{-1})	Ratio (%)
White cherry fruit	Kg	*2.93*	21,123.33	61,891.37	*100.00*
Total output	–	–	–	61,891.37	100.00

Results and Discussion

The white cherry production energy balance was assessed using data obtained from Table 3. Energy consumption related to production was determined to be 16,273.05 MJ ha^{-1}. The largest portion of this energy was attributed to chemical fertilizers (37.73% or 6139.53 MJ ha^{-1}), followed by electrical energy (34.87% or 5674.90 MJ ha^{-1}). Irrigation water comprised 15.18% (or 2470.63 MJ ha^{-1}) of the total energy utilized in production. The majority of the energy utilized in production was specifically associated with nitrogen application, which accounted for 27.60% of the overall energy utilization. It is important to note that the energy usage patterns were consistent with other studies focused on the cultivation of fruits in Türkiye. Energy budget studies also showed that the use of electric power and chemical fertilizers dominate the energy budgets to produce white cherry, as well as other fruits. Studies focused on olive production have also shown that most of the energy utilized in olive production is utilized for irrigation and fertilizer use. Additionally, studies have demonstrated that nitrogen fertilizer utilization has a significant impact on the total energy load associated with olive production. Electrical energy accounts for nearly one-third of the total energy utilized during grape production, and it has been identified as a direct factor influencing yield levels.

Therefore, it is apparent that the use of irrigation pumps is extensive for white cherry production, and there are opportunities for improved energy efficiency. Further, the high utilization rate of fertilizer inputs indicates that N-based feeding practices contribute to increased energy costs. These findings suggest that the energy load associated with fruit production systems in Türkiye is primarily a function of feeding and irrigation, and thus these two components of the production process should be targeted for energy optimization purposes. Ultimately, the positive energy balance associated with white cherry production suggests that the sustainability of the production process could be enhanced through the development of strategies to improve the energy efficiency of irrigation and fertilizer utilization (Table 4).

White cherry production system has shown the highest ratio of energy output to input as indicated by EUE of 4.01, while the specific energy of 0.80 MJ/kg and the energy productivity of 1.37 kg/MJ show that there are very low amounts of loss of energy throughout the production process. The results indicate that white cherry production yields much more energy per unit area than do many other production methods. As an example, Bayramoğlu et al. (2025) showed that energy sustainability of olive production systems is quite low because of the dominance of non-renewable energy inputs with respect to total energy inputs, which resulted in the determination of an EUE of 2.20–2.35. Therefore, white cherry production has demonstrated an advantage over olive production for the purposes of energy sustainability and a moderate level of energy efficiency in comparison to grape production. The fact that the EUE is greater than 3 provides strong evidence that the white cherry production system is an energy efficient system, and that the white cherry production system uses its energy inputs very effectively, and therefore the white cherry production system presents one of the most energy effective and environmentally friendly fruit production models available in Türkiye.

Table 4 Energy use efficiency calculations in white cherry production

Calculations	Unit	Values
White cherry fruit	kg ha^{-1}	21,123.33
EI	MJ ha^{-1}	16,273.05
EO	MJ ha^{-1}	61,891.37
EUE	–	4.01
SE	MJ kg^{-1}	0.80
EP	kg MJ^{-1}	1.37
NE	MJ ha^{-1}	45,618.31

Table 5 Energy inputs in the varieties of energy for white cherry production

Energy groups	Energy input (MJ ha^{-1})	Ratio (%)
DE	8649.08	53.15
IDE	7623.98	46.85
Total	16,273.05	100.00
RE	2534.65	15.58
NRE	13,738.41	84.42
Total	16,273.05	100.00

White cherry production energy input data classifications are listed in Table 5. The total energy of white cherry production is broken down into two categories: 1) direct energy input (8649.08 MJ ha^{-1}; 53.15%) and 2) indirect energy input (7623.98 MJ ha^{-1}; 46.85%), while 84.42% of the total energy comes from non-renewable (13,738.41 MJ ha^{-1}) and 15.58% of the total energy comes from renewable (2534.65 MJ ha^{-1}) energy. This is a reflection of the importance of electricity, diesel fuel, and chemical fertilizers within the production process. Similar observations were made by other researchers who studied Turkish viticulture. In an analysis of Tekirdag vineyards, Say et al. (2024) found that more than half of the energy utilized in the production process came directly from the use of irrigation electricity and diesel fuel. Similarly, Ozalp et al. (2018) noted that non-renewable energy constitutes more than 80% of the energy used in olive production, primarily due to the use of chemical fertilizers and electricity. Additionally, indicated that most of the energy inputs in orchards are associated with fertilizer application and mechanical equipment utilization,

Table 6 Greenhouse gas (GHG) emissions in white cherry production

Inputs	Unit	GHG coefficient (kg CO_{2eq} unit^{-1})	Input used per area (unit ha^{-1})	GHG emissions (kg CO_{2eq} ha^{-1})	Ratio (%)
Human labor	h	0.700	32.66	22.86	1.93
Machinery	MJ	0.071	344.23	24.44	2.06
Farmyard manure	Ton	0.029	146.37	4.24	0.36
Fungicides	kg	6.300	1.66	10.45	0.88
Insecticides	kg	3.940	3.31	12.98	1.09
Nitrogen	kg	1.300	75.03	97.54	8.23
Phosphorus	kg	0.200	109.23	21.85	1.84
Potassium	kg	0.200	56.74	11.35	0.96
Diesel	L	2.760	7.81	21.54	1.82
Electricity	kWh	0.608	1576.36	958.43	80.83
Transportation	kg	0.150	1.97	0.06	0.01
Total	–	–	–	1185.74	100.00
GHG ratio (per kg)	–	–	–	0.06	–

with most of the direct energy usage associated with fuel and electricity to power irrigation systems. The data obtained in white cherry production are consistent with the typical energy profiles seen in orchard systems in Türkiye. The high percentage of non-renewable energy reflects the large amounts of fossil and chemical materials that are used as part of the input structure for the production process. Increasing the use of renewable energy is possible through various methods including the implementation of solar-powered irrigation systems and the use of organic fertilizers. Both methods can decrease energy costs and increase the environmental sustainability of the production process.

According to Table 6, total emissions were estimated at 1185.74 kg CO^2-eq ha^{-1} and the amount of GHG emissions for each product was found to be 0.06 kg CO^2-eq kg^{-1}. The largest proportion of total emissions was caused by electricity usage, which was 80.83% (958.43 kg CO^2-eq ha^{-1}). Nitrogenous fertilizer usage accounted for 8.23% (97.54 kg CO^2-eq ha^{-1}) and machinery usage accounted for 2.06% (24.44 kg CO^2-eq ha^{-1}). Similar to the results reported by Zhang et al. (2021), who studied GHG emissions in Chinese vineyards, electricity and irrigation energy account for approximately 75% of all GHG emissions and pump energy consumption for water is primarily responsible for high levels of emission intensity. Additionally, Martínez et al. (2021), studied the relationship between organic matter application and soil moisture balance in grape production systems located in semiarid regions. They noted that the use of electricity to power irrigation pumps is a direct function of the organic matter applied and that this is a contributing factor to increasing electricity's share of the total GHG load. Similarly, Say et al. (2024), who studied GHG loads in vineyards in Tekirdag, also stated that GHG emissions associated with electricity and nitrous oxide emissions from fertilizer application constituted nearly 85% of the total GHG load. Rashidov et al. (2021), who investigated GHG emissions in perennial vineyard systems using various types of energy sources, found that the selection of an energy source has a significant impact on the total GHG emissions of a system. In addition, they demonstrated that the use of renewable energy sources significantly reduced the emission intensity of these systems. Therefore, improvements in the energy efficiency of irrigation pumps, the encouragement of the transition to renewable energy systems and the optimization of nitrogenous fertilizer usage are key policy options available for decreasing GHG emissions.

Results in this study are similar to the energy ratios in perennial fruit systems reported by Mandal et al. (2002) and Mohammadi et al. (2010). When the energy components were examined, it was found that chemical fertilizers and usage of electricity received a large share of total energy consumption. The effects of both chemical fertilizers and electricity were determined as, respectively, 37% and 34%. This situation is supported by the findings of Ekinci et al. (2020). This coincides with the findings about the great dependence on mineral fertilizers and electricity stats in fruit studies (Ozalp et al. 2018). The energy profile of inputs used in white cherry production, as compared to other fruit systems prevalent in similar climatic conditions, clearly states that nitrogen fertilizers and irrigation electricity in particular are the decisive items. Khoshnevisan et al. (2014) and Lal (2004) indicate that exquisite use of nitrogen fertilizer has the greatest effect on energy intensity and carbon footprint. In the present research the total carbon emissions were calculated as 1185.74 kgCO_2-eq ha^{-1}, with emissions per product being 0.06 kgCO_2-eq kg^{-1}, caused mainly from electricity and nitrogen fertilizer as a total of about 90%. In the same way, Dyer and Desjardins (2006) emphasize that the most part of energy fuelled emissions in the output of agricultural production occur from electrical and fuel consumption. The results indicate that the direct energy consumption in the production of white cherry has much effect, particularly occurring from pumping and cooling activities. By investigating the energy structure in terms of renewable and non-renewable resources, very valuable contours can be achieved concerning the sustainable levels of production. It was determined that 84.6% of the energy used in the production of white cherry is accounted for by non-renewable sources, while 15.4% represents renewable sources. This is a considerable value and is consistent with the findings of Koctürk and Engindeniz (2009) for olive production systems, indicating the continued dependence of fruit production on non-renewable energy inputs. According to Ekinci et al. (2020), increasing the use of renewable energy should certainly be possible especially by integrating solar energy into irrigation pumps and guiding recommended the use of organic fertilizers. The EUE value obtained in white cherry production demonstrates that the production system provides a positive energy phase yet requires modifications in its energy source structure if the product is going to be sustainable.

Conclusion

In conclusion, white cherry production demonstrates a sound performance level in terms of the efficiency of energy produced; however, as the energy structure employed is based on chemical fertilizer and electrical strategies, the carbon emissions increase at a relatively high rate. Therefore, it is hoped that some recommendations will be made to increase the efficiency of energy consumption and to maintain the carbon footprints as low as possible by applying precision agriculture techniques in connection with nitrogen fertilizer applications. Furthermore energy-efficient pumps should be employed in all irrigation systems, and renewable energy sources should be integrated into production systems. Accordingly, establishing a well-defined energy management framework based on sustainable resource use in white cherry production is of critical importance. Such an approach would reduce the environmental footprint of production while supporting the development of a resilient agricultural ecosystem and sustainable income structures for producers.

Conflict of interest M. Bozdemir Akçil, S. Candemir, H.G. Doğan, and Z. Bayramoğlu declare that they have no competing interests.

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