Research Article / Araştırma Makalesi GU J Sci, Part A, 8(4): 424-434 (2021) https://doi.org/10.54287/gujsa.1012834

Gazi University
Journal of Science
PART A: ENGINEERING AND INNOVATION
http://dergipark.org.tr/gujsa

Effect of Wood-Based Panels and Varnish Types on VOC Emissions in Furniture Production

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Keywords

Wood-Based Boards
Furniture
Emission
Varnish
VOC

Abstract

This study investigated the effects of varnishes on VOCs emissions from wood-based panels of standard particle panels (PB) and medium density fiber panels (MDF) which are covered by beech veneer and varnished by three different types of varnishes. The highest value was 624,90 ppm for Toluene, while the lowest was 0,30 ppm for Para xylene in respect to the Particleboards which were covered by beech veneered and varnished with cellulosic varnish. However, samples of beech veneered and varnished with synthetic and polyurethane varnishes yielded less gas emission than cellulosic varnish. The samples of MDF, covered with beech veneer and varnished polyurethane varnished yielded gas emission more than the synthetic (100%) and cellulosic varnishes (220%). All values show that gas emission reduces its effect within time in respect to the manufacturing time, after drying period, 15- and 30-days measurements.

Cite

Çınar, H., Yıldırım, K., & Hamarat, M. (2021). Effect of Wood-Based Panels and Varnish Types on VOC Emissions in Furniture Production. *GU J Sci, Part A*, *8*(4), 424-434.

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Article Process

Submission Date	21.10.2021
Revision Date	03.11.2021
Accepted Date	16.11.2021
Published Date	25.11.2021

1. INTRODUCTION

Air quality is very significant in terms of having healthy life in all aspects of lives and eco design becomes more important day by day. For example, 5 million liters of air as known of oxygen and nitrogen and are inspired by human beings in every year. On the other hand, almost fifty thousand liters of other gases (argon, carbon-dioxide i.e.) are dangerously presented into human body each year with impressive effects on the health issues regarding to the composition. Particularly in doors; offices, houses, hospitals, schools, and so on people mostly spend their time and a particular attention have been paid to the air quality of indoors (Bulian & Fragassa, 2016).

Nowadays, many non-environmentally friendly and polluting building materials can be used in indoor architectural spaces, sometimes knowingly or unknowingly. A number of studies has been carried out on furniture and interiors livable (Subaşı et al., 2017; Hidayetoglu & Müezzinoglu, 2018; Yıldırım et al., 2020; 2021). However, there are few studies on the effect of volatile organic compounds (VOCs) emitted from furniture to the environment. All these pollutants emitted from furniture and equipment elements might have a negative impression on air quality, health issues of people and indoor-outdoor environments (Kephalopoulos et al., 2012). The emission of VOCs for furniture and indoors, coated with paints, varnishes, waxes, and solvents, are discussed by the authors of Missia et al. (2010), Bartzis et al. (2015), Cacho et al. (2013), Nandan et al. (2020) and Ulker et al. (2021). In addition to that, alongside with other sources; other household chemicals, cleaning agents and heating furnaces, cooking appliances and candles also contribute to air concentration of VOCs in living areas. In the last thirty years, the topic of sick building syndrome

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(SBS) becomes to the attention concerned with VOC concentrations and seriously suspected to be adjuvant factors for asthma, allergy and various symptoms (Andersson et al., 1997; Fechter et al., 2006).

Studies show that people working in the construction industry and in environments where furniture and other wood products are manufactured, repaired or restored are frequently exposed to hazardous chemicals (Cinar & Erdogdu, 2018). In recent years, from indoor building materials, a significant approach here were raised with the exposure to VOCs. European Union (EU) Directive No 320 of 29 May 2002 puts limits on the discharge of VOCs from industrial materials, and subsequently, furniture producers have been forced to move toward alternative coating methods for wood and wood-based materials that use fewer volatile organic solvents (Akkuş et al., 2021). Even though the emissions from indoor materials decrease over time (Cinar, 2005; 2018; Brockmann et al., 1998; Benotto et al., 2009; Yu & Kim, 2012; Cinar & Erdogdu, 2018; Cinar et al., 2018), many building materials are repeatedly and periodically being used as interior architectural coatings, remodeling and renovation so on.

Related to the furniture industry regarding ecological concerns, there is a significant tendency for ecological production. The stricter regulations, Kyoto protocol and Paris Climate Changes Agreement and public pressures have accelerated the manufacturers how they do the business. Another significant push was conscious consumers who were aware of the raising need for more ecofriendly products. These movements have pushed the industry for timber harvesting and management, has begun to differentiate products through ecological processes. Moreover, the consumption for wood-based production has greatly affected due to the wood-based panel production to meet the demands from the building and furniture industries. Increased demand has influenced investors, consumers, regulatory agencies, and shareholders to develop their production strategies (Cinar et al., 2018). Not surprisingly, these attempts affect the furniture industry regarding the furniture and wood-based panel productions.

Varnishes and coatings have been used for furniture and wood protection in wider aspects since very ancient times. The use of resin based-based varnishes can be historically traced back to the ancient time such as Egyptian, Persian, Chinese, Greek or Indian culture (Cortina & Carbo, 2004). In the industry, varnishes are classified by ASTM (2019) into four types. These are oil-based (film primarily chemical reaction), bituminous, spirit and spar varnishes. Varnishes are also classified for the polarity as oil or water-based varnishes (Wu et al., 2015; Cheng et al., 2018) and is the highest for ozone formation (Li et al., 2018).

A number of studies on the emissions concerned with varnishes for indoor air pollution (WHO, 1989; Clausen et al., 1991; Howard et al., 1998; McCrillis et al., 1999) shows that cyclic hydrocarbons, saturated aliphatic, oxygenated hydrocarbon and aromatic hydrocarbon have been identified both spirit varnishes and oil-based varnishes (Silva et al., 1998). The major VOCs for oil-based varnishes were identified as ethylbenzene, isobutanol, o-xylene, formaldehyde and m,p-xylene (Howard et al., 1998; Guo et al., 2002; Shun-Cheng et al., 2003).

The literature provides useful information concerned with the facts for the varnish selection when coating wood products and furniture. Experience for the ecological impression for furniture and wood products is a crucial agent for manufactures to develop the production strategies from ecologically approaches for "green" products. In the light of the above information, the hypotheses of this study are given below.

H1: There are significant differences between measurements of VOCs emission values on particleboard (PB) and medium density fiberboard (MDF) wood-based boards covered with varnish.

H2: There are significant differences for the values of VOCs emission in the wood-based panels concerning three different varnish types.

H3: There are differences between the measurement values of VOCs emissions in the wood-based boards at four different times.

2. MATERIAL AND METHOD

2.1. Wood Based Panels

Standard particle panels (PB) with 18 mm thicknesses, manufactured in accordance with TS EN 312 (TSE, 2012) and MDF with 18 mm thicknesses, manufactured in accordance with TS EN 622-5 (TSE, 2011) were analyzed. The samples were veneered by beech with a thickness of 1,0mm and varnished with three types of varnishes; respectively, cellulosic varnish, synthetic varnish and polyurethane varnish. These two types of wood-based panels and three types of varnishes are being commonly used in the furniture industry. The samples for the experiments were supplied from boards of 210x280x0.18 cm in accordance with TS EN 326-1 (TSE, 1999).

2.2. Preparation of Samples

Twenty specimens were prepared from PB and MDF with 18 mm thicknesses. They were dimensioned by cutting into 500 x 500 mm, weighed out with Precia Gravimetrics 312_6200C, in accordance with TS EN 326-1 (TSE, 1999), and each sample was numbered from 1 to 20, varnished with cellulosic, synthetic and polyurethane varnishes respectively. After drying, they were covered with nylon for avoiding emissions (Figure 1), and left at the temperature of 20ºC and 60/65 percent relative humidity in order to obtain a moisture value equal to the internal environmental conditions according to TS EN 2471 (TSE, 1976).

Figure 1. *Number of Samples at Positions and Keeping Samples for Experiment*

2.3. Experiment Implementation

Gas emissions were measured from newly veneered and edge covered PB and MDF, were left in store less than three days. Specimens were put into the Climatic Test Cabinet TK600NUVE (2012) at 20ºC and 65 % relative humidity for the 1^{st} measurements, which were taken by a multi- RAE multiple gas analyzer at 1, 2, and 3 hours over the test specimen prepared from boards supplied immediately from the factory in accordance with TS EN 13986 (TSE, 2015) and test method TS EN 717-1 (TSE, 2006). The measurements of TK600NUVE cabinet were 75 by 75 by 132 cm, and a multi-RAE multiple gas analyzers were installed to the cabinet (Figure 2 and 3).

Figure 2. *Climatic Test Cabinet*

Figure 3. *FTIR Spectrum Two ™ Gas Analyzer*

This study determined the effects of varnishes on nButylacetate, Toluene, Acetone, Isopropanol, Isobutylacetate and Paraxylene emissions for cellulosic, synthetic and polyurethane varnishes were determined and synthesized with the accepted limit values as ppm (per million particular part). Eco-Indicator 99 (Goedkoop & Spriensma, 2000) was used to check the quantitative data representing VOC emission, which was measured according to TS EN 717-1 (TSE, 2006) by a FTIR SpectrumTwo ™ Gas analyser.

2.4. Statistical Analysis

In order to carry out the effects of VOCs emission on varnished wood-based panels, data obtained from the measurements were summarized for understanding and comparing with the eco indicator results. Measurements of the VOCs emission in two different types of varnished wood-based boards (PB and MDF) were accepted as "dependent variables", whereas, the measurement time with wood-based board type and the varnish type were accepted as "independent variables." Afterwards, multivariate analysis of variance (MANOVA) was used to measure the effects of interactions between independent variables (board type X varnish type X time) depending on the measurement values of VOCs emission for the dependent variables. In addition, one-way analysis of variance (ANOVA) was used to examine the effect of differences in board type, varnish type, and measurement time (production moment, after drying, on the 15th day and 30th day) on VOCs emission in wood-based boards. The mean values found to be important in the analysis of variance are presented in graphic form.

3. RESULTS

Cronbach's Alpha test was used for reliability of dependent variables, and evaluations of values for VOCs emissions for examining. A coefficient of internal consistency of the Cronbach for two scales based on the VOC emissions measurement values are as follows: Particleboard (PB): 0.66; and Medium Density Fiberboard (MDF): 0.67. The reliability of the scale, which covers the measurement values of all dependent variables, is 0.67. Studies of Cronbach (1951) and Panayides (2013) state that the alpha reliability coefficients for all dependent variables could be accepted as 'reliable' while it is above 0.60. This scale is reliable.

According to data obtained from the study, the differences among each independent variable evaluated and VOCs emission values variance analyzes were carried out and performed to determine the differences between board type * VOCs emission values, varnish type * VOCs emission values and time * VOCs emission values.

First, the effects of interactions for independent variables (board type X varnish type X time) depending on the measurement values of the VOC emission for dependent variables (nButylacetate, Toluene, Acetone, Isopropanol, Isobutylacetate and Paraxylene) were tested by using the multivariate analysis of variance (MANOVA) and given in Table 1.

Table 1. *MANOVA, Independent Variables*

Independent Variables	**F**	**df**	**Sig.**
Board type	1.305	6	0.0263^{ns}
Varnish type	37.314	12	0.000*
Time	7.424	18	0.000*
Board type*Varnish type	0.823	12	0.627^{ns}
Board type*Time	0.703	18	0.808^{ns}
Varnish type*Time	7.091	36	0.000*
Board type*Varnish type*Time	0.808	36	0.782^{ns}

Note: * α: 0.001 is the level of significance, ^{ns}: Not significant.

According to Table 1, the main effects (varnish type and time) and the two-way interaction for varnish type*time were found to be significant at a level of $p < 0.001$. However, the main effect of board type, board type*varnish type and board type*time two-way interactions with board type*varnish type*time triple interaction were insignificant (at a level of $p < 0.05$). Accordingly, binary and triple comparisons of board type do not influence VOCs emission measurement values. In other words, changing any varnish type or time factor in any board type did not significantly affect the total VOCs emission measurement value.

In another analysis, the ANOVA test results for the categorical averages, values of standard deviation and data obtained for differences for the measurement values of the VOCs emissions in the wood-based panels coated with varnish (PB and MDF) are given in Table 2.

Table 2. *The ANOVA, Average Values, Standard Deviation and the Dependent Variables Related to the VOCs Emissions According to Wood-Based Panels*

Dependent Variables	**Wood-Based Boards**				**ANOVA Results**		
	Particleboard (PB)		Fiberboard (MDF)				
	M	SD	M	SD	F	df	Sig.
nButylacetate	35,696	66,452	35,609	72,045	0,000	1	0,995^{ns}
Toluene	94,051	182,463	85,537	180,128	0,066	1	0,797^{ns}
Acetone	10,734	50,268	11,157	38,463	0,003	1	0,959^{ns}
Isopropanol	2,655	27,719	2,443	32,549	0,001	1	0,970^{ns}
Isobutylacetate	5,948	11,625	5,539	11,514	0,038	1	0,846^{ns}
Paraxylene	2,173	3,094	1,776	2,704	0,555	1	0,458^{ns}

Notes: ns: The differences among the groups are not significant at the level of p<0.05.
M: Average value, SD: Standard deviation, F: F value, df: Degree of freedom.

According to Table 2, the differences for the dependent variables including the measurement values of the VOCs emissions in the panels were not found statistically significant (at a level of $p < 0.05$) in terms of all the dependent variables related to the scale. These results show that the board type has no effect on the

VOCs emission values measured from both wood-based boards covered with varnish. Figure 4 shows the graphical results.

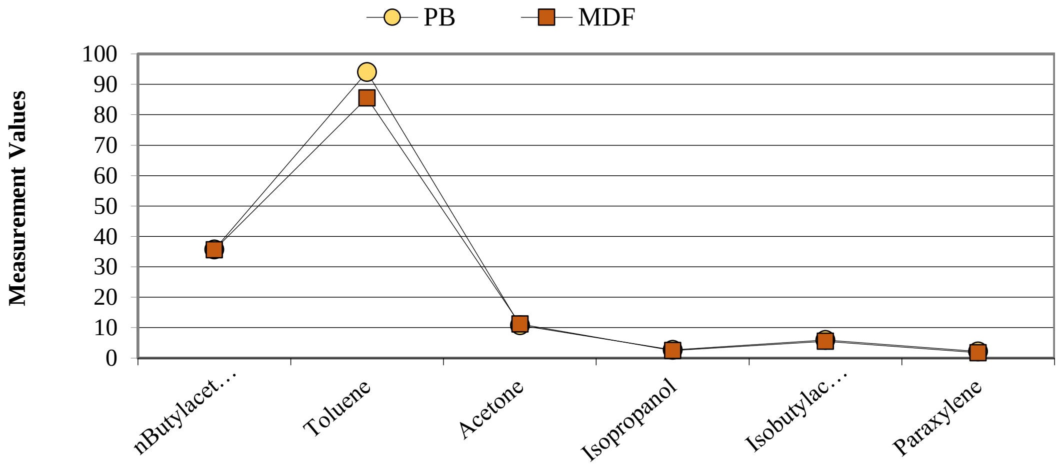

Figure 4. *Effect of the Wood-Based Board Types on the VOC Emissions*

According to Figure 4, the average measurement values of the VOC emissions in the boards covered with varnish are very close to each other for all the dependent variables related to the scale. There is no difference between the VOC emission measurements of both boards. This result shows that the H1 hypothesis, "*There are significant differences between measurements of VOCs emission values on particleboard (PB) and medium density fiberboard (MDF) wood-based boards covered with varnish*" was not supported.

The ANOVA test results for the data obtained for the differences between the measurement values of the VOCs emissions in boards using three different varnish types (cellulosic, synthetic and polyurethane varnish) are given in Table 3.

Table 3. *ANOVA Test Results of the Dependent Variables Related to the VOCs Emissions According to Varnish Type*

Dependent Variables	Varnish Type						ANOVA Results		
	Cellulosic Varnish		Synthetic Varnish		Polyurethane Varnish				
	M	SD	M	SD	M	SD	F	df	Sig.
nButylacetate	31,093	43,321	4,369	9,039	71,495	101,151	11,243	2	0,000*
Toluene	191,977	267,658	12,582	15,068	64,822	100,876	12,452	2	0,000*
Acetone	38,469	66,045	-0,344	1,453	-5,287	22,780	14,112	2	0,000*
Isopropanol	21,337	42,206	-2,065	3,823	-11,624	19,477	15,864	2	0,000*
Isobutylacetate	10,503	15,599	-0,074	1,323	6,802	10,046	9,991	2	0,000*
Paraxylene	0,688	0,492	1,700	1,616	3,507	4,299	11,250	2	0,000*

Notes: *: The differences among the groups are significant at the level of p<0.001.
M: Average value, SD: Standard deviation, F: F value, df: Degree of freedom.

According to Table 3, the differences for the dependent variables including the measurement values of the VOCs emissions in the boards using three different varnish types were found to be statistically significant at a level of $p < 0.001$ in terms of all the dependent variables related to the scale. These results show that the varnish type has effect on the VOCs emission values measured from both boards covered with varnish. The result is given Figure 5.

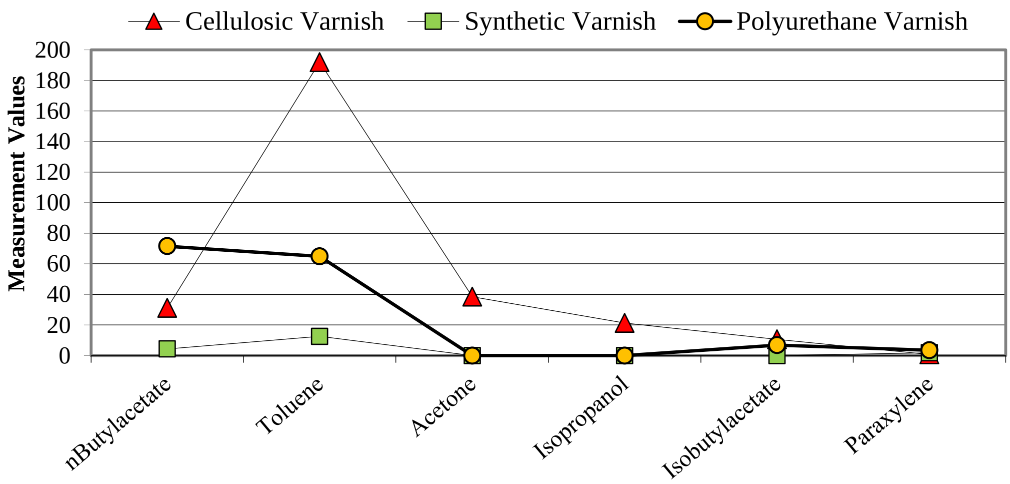

Figure 5. *Effect of the Varnish Types on the VOC Emissions*

According to Figure 5, the average measurement values of the VOCs emissions in the boards using three different varnish types were found to be quite different for all the dependent variables related to the scale. The figure shows that there are significant differences for the average measurement values of VOCs emissions in the boards using three different varnish types. This result supports the H2 hypothesis, which asserts "*There are significant differences between for the values of VOCs emission from wood-based panels using three different varnish types*". According to these results, it can be said that the board using cellulosic varnish gives more toluene gas release compared to the panels using other varnishes.

Table 4 gives ANOVA test results of the differences for the measurement values of VOC emissions in the panels at four different times (production moment, after drying, on the 15th day and 30th day).

Table 4. *The Average, Standard Deviation and ANOVA Test Results of the Dependent Variables Related to the VOC Emissions According to Measurement Time*

Dependent Variables	Measurement Time								ANOVA Results		
	Production Moment		After Drying		15th Day		30th Day				
	M	SD	M	SD	M	SD	M	SD	F	df	P
nButylacetate	106,469	106,242	28,690	28,009	6,144	10,107	1,307	3,274	23,354	3	0,000*
Toluene	282,877	268,754	68,928	84,522	6,126	8,561	1,243	1,744	26,461	3	0,000*
Acetone	38,395	83,075	6,947	12,903	-0,901	1,475	-0,658	0,629	5,909	3	0,001*
Isopropanol	14,847	57,456	-3,117	13,435	-1,646	4,376	-0,112	1,956	2,361	3	0,075*
Isobutylacetate	18,309	16,367	5,036	5,998	0,035	1,849	-0,406	0,928	29,704	3	0,000*
Paraxylene	4,5819	4,530	1,981	1,512	0,799	0,749	0,492	0,489	17,313	3	0,000*

Notes: *: The differences among the groups are significant at the levels of $p<0.10$ and $p<0.001$.
M: Average value, SD: Standard deviation, F: F value, df: Degree of freedom.

Table 4 gives ANOVA results for the differences for the dependent variables including the values for VOCs emissions in the panels at four different times, were found to be statistically significant at a level of $p < 0.001$ in terms of all the dependent variables. These results show that the measurement time has effect on the VOCs emission values measured from both boards covered with varnish. Figure 6 gives the values after drying, 15th day and 30th day results.

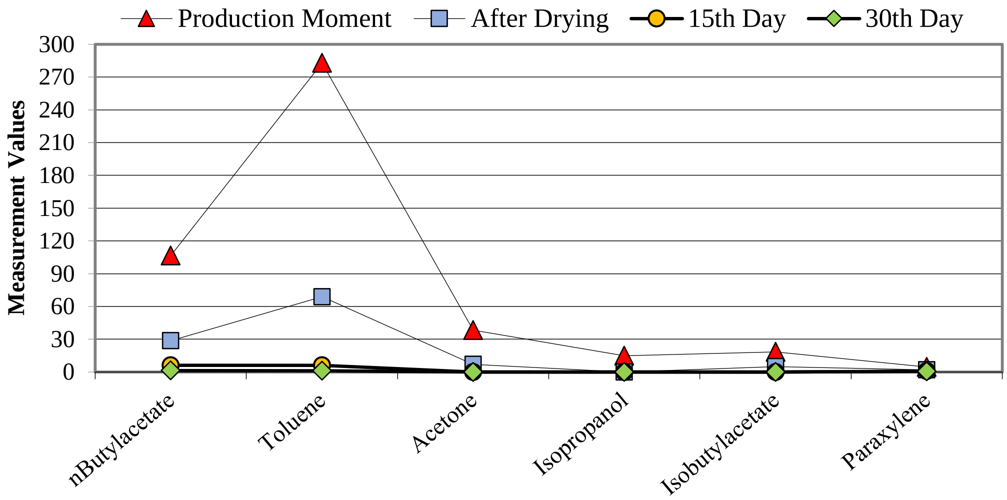

Figure 6. *Effect of the Measurement Time on the VOCs Emissions*

The average values of VOCs emissions in the boards using three different varnish types were found to be quite different for all the dependent variables related to the scale according to Figure 6. The figure shows that there are significant differences for the average measurement values of VOCs emissions in the boards at four different times. The H3 hypothesis, is supported, asserts "*There are differences between the measurement values of VOCs emissions in the wood-based boards at four different times*". According to these results, it is seen that the VOCs emission value is reset on the 30th day in the measurements made on the boards.

4. CONCLUSION

This paper analyzed the effects of varnishes on nButylacetate, Toluene, Acetone, Isopropanol, Isobutylacetate and Paraxylene emissions for cellulosic, synthetic and polyurethane varnishes for VOCs. The following conclusion can be made:

- ✓ The highest value was **624,90 ppm for Toluene**, while the lowest was **0,30 ppm for Para xylene** in respect to the Particleboards which were covered by beech veneered and varnished with cellulosic varnish. However, samples of beech veneered and varnished with synthetic and polyurethane varnishes yielded less gas emission than cellulosic varnish.
- ✓ The samples of MDF, covered with beech veneer and varnished polyurethane varnished yielded gas emission more than the synthetic (100%) and cellulosic varnishes (220%).
- ✓ In accordance with the results, it can be said that cellulosic, synthetic and polyurethane varnishes, which are widely used in the sector in terms of protection and visual appearance, are not considered as environmentally friendly.

Considering manufacturing furniture, raw materials and semi-finished materials in line with the product life cycle, selection and application of varnishes used for protection are significantly important in terms of environmentally friendly products. All values show that gas emission reduces its effect within time in respect to the manufacturing time, after drying period, 15- and 30-days measurements. After the application of varnishes, it is important to make ventilation frequently daily and to ensure air circulation in closed environments.

Giving a thought into the number of products, components, elements and agents in the furniture industry and interiors for design projects, it is possible to say that there is a high responsibility for designers in order to be aware of the consequence of their work for ecological aspects for the eco-friendly and sustainable production and are supposed to start taking into account eco design issues concerned with the impacts on the environment.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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