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Energy Vulnerability and Quality of Life in Moldova: an Empirical Analysis and Sustainable Transition Policy

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Abstract

As a small open economy dependent on energy imports, Moldova is particularly vulnerable to crises, as has been evident over the past five years. Energy crises and price shocks have made the population and economy more vulnerable, highlighting the importance of assessing energy vulnerability and its impact on quality of life. This article introduces a new Energy Vulnerability Index (EVI) for Moldova, which considers the country's unique characteristics. This index's practical significance lies in its potential for monitoring government strategies and programmes. The developed index consists of four pillars: structural vulnerability, consumer vulnerability, energy balance vulnerability and inflation vulnerability. The paper's main objective is to prove or disprove the hypothesis that growing energy vulnerability has a statistically significant negative impact on quality of life. Another objective of the study is to evaluate the impact of the government's policy of partially compensating the population for energy resources consumed. To test this hypothesis, a multiple linear equation was constructed using EViews software. The results confirmed the hypothesis and revealed that unemployment, in addition to energy vulnerability, negatively affects quality of life. The following factors were found to have a positive effect: the share of the urban population, the share of the population with higher education, and government compensation policy. Based on these findings, policy recommendations were developed, focusing on two strategies: strengthening social protection systems and implementing reforms to increase energy efficiency and green energy production.

Keywords:
energy poverty, energy vulnerability, socioeconomic inequality, quality of life, resilient policy

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I. Introduction

Moldova, as a country-candidate for European Union membership, has reoriented all its trade flows to the European market and has also opened its market to European goods that are not subject to duties. The integration of the Moldovan market into European trade flows has led to the fact that the national economy is subject to the same economic ups and downs as the European one. The energy crisis has hit the socio-economic development of the country. And, since Moldova's level of economic growth and the well-being of the population are much lower, the country's citizens are more vulnerable compared to Europeans. The government is taking measures to reduce the energy vulnerability of the population. But there are no studies to assess whether the implemented measures have a positive effect and whether they have reduced the energy vulnerability and enhanced the quality of life. The answer to this question is one of the objectives of this work.

Thus, the study of the country's energy vulnerability is especially relevant in the current period, when the volatility of energy prices has increased and price shocks have become more frequent. According to the United Nations Development Programme (UNDP) estimates, in 2022, electricity prices increased fivefold, and natural gas prices sevenfold compared to 2021. As a result, more than 70% of households spent more than 10% of their income on energy resources, which indicates that in 2022, more than two-thirds of the Moldovan population was energy vulnerable [1]. However, no Index assesses Moldova's energy vulnerability, taking into account the country's specifics, so the development of this index is not only one of the objectives of the study, but is also a novelty. The main objective of the study is to test the hypothesis about the negative impact of energy vulnerability on the quality of life.

This paper has both theoretical and practical significance. In this paper, a new composite Energy Vulnerability Index (EVI) is developed for Moldova to empirically assess its impact on the quality of life of the population. Thus, the theoretical significance consists in creating an EVI that consists of four pillars, and each pillar includes 2-4 indicators. The practical significance consists in assessing the impact of energy vulnerability on the quality of life of the population of Moldova and answering the question of whether the policy measures taken by the government to mitigate this impact are effective.

II. Conceptual perspectives on energy vulnerability

There are only a few scientific papers that assess energy vulnerability. Mostly, energy poverty is studied, not vulnerability. Djoudji and Nguea argue that energy vulnerability depends primarily on access to reliable energy sources [2]. The authors identify poverty with

vulnerability, but these are different concepts. Energy poverty indicates a situation where the population either lacks access to energy sources [3] or cannot afford to purchase them in the required quantities [4], due to limited financial resources. In our view, energy vulnerability is the likelihood of falling into energy poverty. Energy poverty can be classified under ex-post analysis, and energy vulnerability under ex-ante analysis.

Before the energy crisis and the aggravation of geopolitical contradictions, the problem of energy resource availability (energy poverty) became increasingly solvable for countries of the world as the globalization process was developing. The breakdown of supply chains led to a shortage of cheap energy sources. A decrease in supply inevitably leads to higher prices not only for energy resources but also for other goods, since the increased price of these resources is included in the cost of final consumer goods. Today, there are no goods whose production does not require energy. Thus, the solvency of the population has decreased, and energy resources have become less accessible not physically, but financially. As a result, both energy poverty and energy vulnerability have increased even in developed countries.

We believe that one of the factors that leads to an increase in energy vulnerability is the volatility of energy prices; therefore, one of the pillars selected in the development of the Energy Vulnerability Index was inflation vulnerability. In the few scientific papers that propose an algorithm for calculating the EVI, the emphasis is mainly on import dependence and market concentration. D. Guarascio et al., in their published work, assess the energy vulnerability of the economies of the EU countries, not the population; therefore, in addition to the listed indicators, they also take into account the share of energy-intensive industries [5].

Innovation and investment in green energy contribute to economic growth [6] and increased welfare [7]. Thus, one way to reduce both energy poverty and energy vulnerability is to switch to Renewable Energy Sources (RES) [8]. Therefore, the indicator that assesses the share of RES energy in gross domestic consumption is taken into account in the Energy Vulnerability Index developed in this article. The concept proposed by the authors differs from the concepts of other scientists. For example, A. Gatto and F. Busato, when assessing global energy vulnerability, found that countries with a colder climate, developed industrial countries with a high level of demand for energy resources, are more vulnerable [9]. The concept proposed in this paper is based on the idea that energy vulnerability is based on the structural, consumer, energy balance, and inflation vulnerability.

III. The proposed methodology for assessing energy vulnerability

The novelty of this work is the development of the methodology for calculating the Energy Vulnerability Index. During the development, the authors were guided by the following criteria. Firstly, the methodology should be easily reproducible by any researcher. Secondly, it should take into account the specifics of Moldova. Thirdly, the indicators included in the index were selected based on their theoretical relevance and data availability for Moldova. The selected indicators were grouped into four pillars: structural vulnerability, consumer vulnerability, energy balance vulnerability, and inflation vulnerability (Table 1). The calculation of the EVI is carried out in *three stages*.

Table 1: *Structure of the Energy Vulnerability Index of Moldova*

Abbreviation	Indicator	Justification	Units
	Pillar 1: Structural Vulnerability (SV)		
EIN	Energy imports, net (% of energy use)	Measures overall dependence on external supplies	%
HHII	Herfindahl-Hirschman Index for gas and electricity imports	Measures the risk associated with the dominance of one importer of gas and electricity	Index (0-1 scale)
VEIG	Value of energy imports as a percentage of Gross Domestic Product	Measures the macroeconomic burden on the economy	%
	Pillar 2: Consumer Vulnerability (CV)		
SHEE	Shares of home energy expenditure in total consumption	Reflects financial pressure on the population	%
SEFC	Share of expenses on firewood and coal in total consumption	Reflects the lack of access to modern energy sources	%
	Pillar 3: Energy Balance Vulnerability (EBV)		
SRE	Share of renewable energies in gross electricity consumption	Measures a country's ability to meet its own electricity needs with electricity produced from renewable energy sources	%
SEL	Share of electricity losses in gross electricity consumption	Measures the efficiency of supplying electricity to consumers	%
	Pillar 4: Inflation Vulnerability (IV)		
ECPI	Electricity consumption price index	Reflects instability in electricity prices	%, previous year=100%
GCPI	Natural gas consumption price index	Reflects instability in natural gas prices	%, previous year=100%
HCPI	Hot water consumption price index	Reflects instability in hot water prices	%, previous year=100%

CCPI	Central heating consumption price index	Reflects instability in central heating prices	%, previous year=100%

Source: The authors' elaboration

Considering that the units of measurement of the indicators listed in Table 1 are not identical, and to correctly combine them into one index, at *the first stage*, all time series of indicators were normalized using the "min-max" scaling method. Depending on the sign of the influence, the corresponding normalization formula was used. For example, for the indicator "Share of renewable energies in gross electricity consumption," the growth of which negatively affects energy vulnerability, the following normalization formula was used:

$$x'_{t(-)} = \frac{x_{max} - x_t}{x_{max} - x_{min}} \quad (1)$$

Where,

x'_t – the normalized value of the variable x in year t,

x_{max} – the maximum value of the variable x,

x_t – the value of the variable x in year t,

x_{min} – the minimum value of the variable x.

To ensure comparability of all other indicators, the growth of which increases energy vulnerability, the following normalization formula was used:

$$x'_{t(+)} = \frac{x_t - x_{min}}{x_{max} - x_{min}} \quad (2)$$

In *the second stage*, the value of the pillars is calculated using the arithmetic mean method, and in *the third stage*, the EVI is calculated. The weight of the first two pillars is higher, since their impact on energy vulnerability is also higher. The calculation results are shown in Table 2.

$$EVI = 0.3 \times SV + 0.3 \times CV + 0.2 \times EBV + 0.2 \times IV \quad (3)$$

Table 2: *Level of the Energy Vulnerability Index of Moldova*

Year	Structural Vulnerability (SV)	Consumer Vulnerability (CV)	Energy Balance Vulnerability (EBV)	Inflation Vulnerability (IV)	Energy Vulnerability Index (EVI)
2010	0.4665	0.1433	0.9088	0.2905	0.4228
2011	0.6226	0.3509	0.8413	0.3138	0.5231
2012	0.4636	0.6494	0.8966	0.1602	0.5453
2013	0.4654	0.7565	0.7656	0.1291	0.5455
2014	0.3369	0.8020	0.5994	0.1248	0.4865
2015	0.1965	0.5521	0.4408	0.1841	0.3496
2016	0.1924	0.6786	0.5526	0.1646	0.4047
2017	0.2652	0.8636	0.5055	0.1958	0.4789
2018	0.3414	0.9838	0.4664	0.0975	0.5103
2019	0.3581	0.2354	0.3978	0.1180	0.2812
2020	0.2280	0.2557	0.3618	0.1323	0.2439
2021	0.3800	0.1254	0.2666	0.1034	0.2256
2022	0.9179	0.4871	0.2622	1.0000	0.6739
2023	0.5363	0.6944	0.0294	0.5718	0.4895

Source: The authors' computation

As expected, the highest level of energy vulnerability was recorded in 2022. The main reason is the energy crisis, as a result of which the Consumer Price Index (CPI) for natural gas was 322% (previous year = 100%), and for electricity and central heating, respectively, 156% and 162%. The energy crisis had the most significant impact on inflation vulnerability and structural vulnerability. The energy balance vulnerability in 2022 did not change significantly compared to 2021, as the production of electricity from renewable energy sources increased by 1.3 times compared to the previous year.

In the following year (2023), energy vulnerability has decreased, but its level is still relatively high and corresponds to the level recorded in 2014 and 2017. The main factors that led to the decrease in the EVI in 2023 are the growth of electricity production from RES by 1.5 times, a reduction of electricity losses by 3 thousand tons of oil equivalent, and a decrease in energy imports, net (% of energy consumption) by 8.3% compared to 2022.

An analysis of the relationship between the EVI and the absolute poverty level showed that in 2010-2017 and 2021-2022, the periods of growth and decline of both indicators coincide (see Fig.1). This relationship is logical, since the group of the population that lives below the absolute poverty line is most susceptible to energy vulnerability.

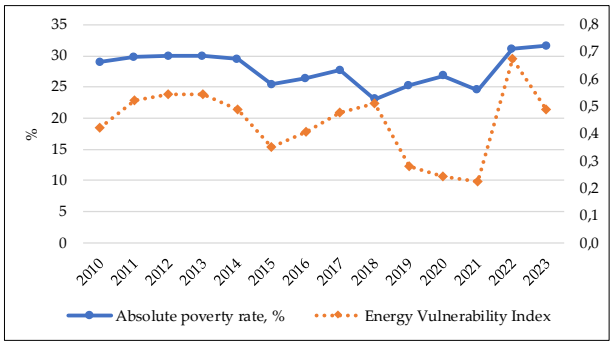


Figure 1: *Evolution of Absolute Poverty Rate and Energy Vulnerability Index, 2010-2023*

As we have already noted, the highest level of energy vulnerability was registered in 2022. In the same year, not only did the absolute poverty rate increase significantly (by 6.6 percentage points), but so did the depth of absolute poverty (by 1.2 percentage points) and the severity of absolute poverty (by 0.3 percentage points). It is the highest growth for the analyzed period. The depth of poverty reflects the level of the average deficit in population consumption necessary to overcome the poverty line. Inequality exists not only between the rich and the poor, but also among the poor, especially in

Moldova. The indicator "the severity of absolute poverty" reflects the distribution of the level of well-being of the poor relative to the poverty line. On average, one-third of the country's citizens live below the poverty line.

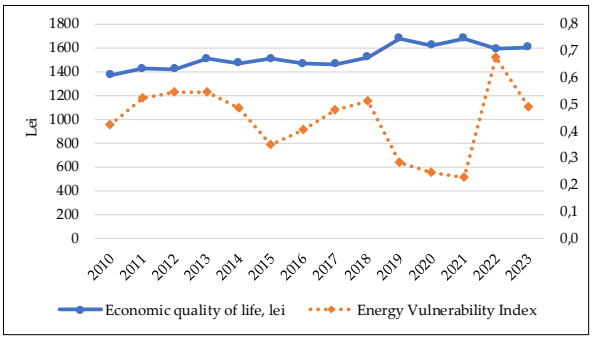


Figure 2: *Evolution of Economic Quality of Life and Energy Vulnerability Index, 2010-2023*

A comparative analysis of the dynamics of the EVI and economic quality of life showed that a significant decrease in energy vulnerability in 2015 (by 0.1369), 2019 (by 0.2291), and 2023 (by 0.1844) led to an increase in the economic quality of life (see Fig.2). An increase in energy vulnerability in 2012 (0.0222), 2016 (0.0551), 2017 (0.0742), and 2022 (0.4483) led to a decrease in the quality of life.

Thus, it can be assumed that there is an inverse relationship between these two indicators. The hypothesis about the negative impact of energy vulnerability on the quality of life is tested in the following paragraph.

IV. Empirical strategy: testing the impact of energy vulnerability on quality of life

Econometric models were developed to test the central hypothesis. In this section, multiple linear regression models are described and tested in detail. Table 3 describes the dependent (endogenous) variable and independent (exogenous) variables.

Table 3: *Endogenous variable and exogenous variables*

Abbreviation	Indicator	Justification	Units
	Endogenous variable		
EQL	Economic Quality of Life	Reflects the financial capacity of the population to meet its requirements	Lei
	Exogenous variables		
EVI	Energy Vulnerability Index (index was expressed as a percentage)	Reflects the likelihood of energy poverty	%
UR	Unemployment Rate	Measures the share of the labor force who do not have a job and are looking for one	%
SCE	State Compensation (partial) for the population's energy consumption	Reflects whether or not the population received compensation for energy consumption	0 – no compensation, 1 - there is
SUP	Share of Urban Population	Measures the share of people living in urban areas	%
PTE	Share of Population with Tertiary Education	Measures the share of people with higher education	%

Source: The authors' elaboration

A correlation matrix was calculated to avoid multicollinearity (Table 4). SUP has the strongest positive correlation with EQL (0.8112). This indicates that with the growth of the urban population, there is a significant increase in the economic quality of life. There is also a strong positive correlation between PTE and EQL (0.7688). This indicates that obtaining higher education provides a higher quality of life. There is a moderate negative correlation between EVI and EQL (-0.4722).

Table 4: *Correlation matrix*

	EQL	EVI	UR	SCE	SUP	PTE
EQL	1	-0.4722	-0.5871	0.3295	0.8112	0.7688
EVI	-0.4722	1	0.0610	0.4627	-0.1125	-0.2701
UR	-0.5871	0.0610	1	-0.25041	-0.6062	-0.8579
SCE	0.3295	0.4627	-0.2504	1	0.7564	0.3341
SUP	0.8112	-0.1125	-0.6062	0.7564	1	0.7368
PTE	0.7688	-0.2701	-0.8579	0.3341	0.7368	1

Source: The authors' computation

This means that with increasing energy vulnerability, the quality of life of the Moldovan population decreases. The strongest negative correlation was recorded between UR and EQL (-0.5871). This negative relationship is logical, as unemployment increases, the economic quality of life declines. Analysis of the relationship between independent variables showed that a strong negative correlation was found between PTE and UR (-0.8579), and a strong positive correlation between SUP and SCE (0.7564), and between SUP and PTE (0.7368).

We will not include these pairs of variables in the same model. If one of these variables is included in the model, the other will not be included. Thus, if one of the independent variables in the model is SUP, neither SCE nor PTE will be included in this model. The same principle was used in the case of the PTE variable. Before building the

model, the Variance Inflation Factor (VIF) was calculated to verify the absence of multicollinearity among the independent variables. The results are presented in Table 5.

When selecting independent variables for future models, the authors were guided by the following criteria. First, one of the exogenous variables should be the "Energy Vulnerability Index," since the primary goal of this study is to test the hypothesis about the negative impact of energy vulnerability on the quality of life of the population. Second, the following pairs of independent variables, PTE with UR, SUP with SCE, and SUP with PTE, cannot be included in the models. The calculation results showed that in all three cases, there is no multicollinearity, since Centered VIF is approximately equal to one, varies in the range [1; 1.8], i.e., less than five.

Table 5: *Variance inflation factors estimates*

Variables	Coefficient variance	Uncentered VIF	Centered VIF
	Model 1		
C	5501.243	25.84021	NA
EVI	1.848950	18.25589	1.328895
UR	149.9760	16.15983	1.114234
SCE	2455.869	1.647943	1.412523
	Model 2		
C	108108.9	526.6284	NA
EVI	2.301959	23.57126	1.715815
PTE	121.6130	422.6298	1.517869
SCE	3001.680	2.088859	1.790450
	Model 3		
C	297581.9	1922.755	NA
EVI	1.024521	13.91493	1.012904
UR	154.7189	22.93194	1.581177
SUP	155.1894	1635.433	1.595487

Source: The authors' computation

The following three multiple linear regression models were estimated using the EViews software, which not only allow us to prove that energy vulnerability has a negative impact on economic quality of life, but also allow us to measure how much an increase in energy vulnerability reduces the standard of living. But since in multiple linear regression models, the value of the coefficient of dependence of quality of life on energy vulnerability is different, depending on what other economic factors are included in the model, it is necessary to check the quality of the models and choose one. This multiple linear regression model will answer the question of how much the economic quality of life will increase if energy vulnerability decreases by one percentage point.

Model 1.

$$EQL = 1873.08 - 5.28 \times EVI - 29.93 \times UR + 146.80 \times SCE \quad (4)$$

Model 2.

$$EQL = 929.82 - 3.99 \times EVI + 28.25 \times PTE + 109.44 \times SCE \quad (5)$$

Model 3.

$$EQL = -296.70 - 2.90 \times EVI - 11.45 \times UR + 49.56 \times SUP \quad (6)$$

To test the null hypothesis H0, about the statistical insignificance of individual coefficients for the regressor, the Student's t-test was used; the results are presented in Table 6. H0 is not rejected for the UR variable of Model 3, which means the regression coefficient of this variable is zero. We excluded this variable and the constant (C) from the linear regression equation (6), but repeated testing has already shown that the determination coefficient is less than 0.5. Thus, we reject Model 3. If we set the significance level to 5%, then in the case of Model 1, the null hypothesis is rejected for all coefficients. Model 2 can be accepted only if we increase the significance level to 10%.

Table 6: *Assessing the statistical insignificance of regression coefficients (Models 1, 2, and 3)*

Variables	Model 1		Model 2		Model 3	
	t-value	*p-value*	*t-value*	*p-value*	*t-value*	*p-value*
C	25.25381	0.0000	2.827929	0.0179	-0.543893	0.5984
EVI	-3.882208	0.0030	-2.628335	0.0252	-2.868402	0.0167
UR	-2.443769	0.0346	-	-	-0.920360	0.3791
SCE	2.962249	0.0142	1.997446	0.0737	-	-
SUP	-	-	-	-	3.978215	0.0026
PTE	-	-	2.562044	0.0283	-	-

Source: The authors' computation

Some quality assessment tests were conducted for multiple linear regression models 1 and 2. The results obtained are approximately the same (Table 7).

In the case of the first model, 75.28% of the variance of the dependent variable is explained by the regression equation 4, and for the second model, the determination coefficient is 76.16%.

Table 7: *Evaluation of the quality of the regression equation (Models 1 and 2)*

Indicators	Model 1	Model 2
R-squared	0.752803	0.761638
Adjusted R-squared	0.678643	0.690130
Standard Error of the Regression	54.59419	53.60961
Sum of Squared Residuals	29805.26	28739.90
Log likelihood	-73.50882	-73.25403
F-statistic	10.15117	10.65102
Probability (F-statistic)	0.002226	0.001864
Akaike info criterion	11.07269	11.03629
Schwarz criterion	11.25528	11.21888
Hannan-Quinn criterion	11.05579	11.01939
Durbin-Watson statistic	1.837451	1.754363

Source: The authors' computation

Testing the residual autocorrelation (Table 8) using the Breusch-Godfrey test showed that there are no statistically significant signs of autocorrelation up to the 2nd order in the models.

Table 8: *Testing autocorrelation (Breusch-Godfrey test)*

Model 1			
F-statistic	0.002100	Prob. F (2,8)	0.9979
Obs. × R-squared	0.007345	Prob. Chi-Square (2)	0.9963
Model 2			
F-statistic	0.038804	Prob. F (2,8)	0.9621
Obs. × R-squared	0.134509	Prob. Chi-Square (2)	0.9350

Source: The authors' computation

The Breusch-Pagan-Godfrey test was used to detect deviations from homogeneity of errors (heteroscedasticity) (Table 9). If "Prob. F" and "Prob. Chi-Square" are above 0.05, there is no reason to reject the H0 of homoscedasticity of residuals. In models 1 and 2, there are no statistically significant signs of inequality of residual variances.

Table 9: *Heteroskedasticity test*

Model 1			
F-statistic	0.603011	Prob. F (3,10)	0.6277
Obs. × R-squared	2.144670	Prob. Chi-Square (3)	0.5429
Scaled explained SS	1.073043	Prob. Chi-Square (3)	0.7836
Model 2			
F-statistic	0.485082	Prob. F (3,10)	0.7001
Obs. × R-squared	1.778525	Prob. Chi-Square (3)	0.6196
Scaled explained SS	0.441415	Prob. Chi-Square (3)	0.9316

Source: The authors' computation

Both models passed all tests and proved the hypothesis of the negative impact of energy vulnerability on quality of life. However, it should be noted that in the case of Model 2, H0 was rejected, and the regression coefficients are different from zero only if we set the significance level at 10%. If we set 5%, then this model should be rejected, and as a result, Model 1 remains. According to this model, decreasing energy vulnerability by one percentage point, ceteris paribus, generates an increase in the economic quality of life by 5.28 lei on average per month.

V. Conclusion

The novelty of this study is the development and calculation of a composite Energy Vulnerability Index (EVI) for Moldova, which reflects both external and internal risks. The relevance of the index is high. Firstly, since the developed index consists of four pillars, it allows for a separate analysis of structural vulnerability, energy balance vulnerability, consumer vulnerability, and inflation vulnerability. Secondly, the EVI can be used to monitor the implementation of government policies in both the social and energy fields.

In addition to developing the EVI, the aim of the study is to test the hypothesis about the negative impact of energy vulnerability on the quality of life. The constructed multiple linear regression model has proven this hypothesis. Each percentage point reduction in energy vulnerability brings an average increase of 5.28 lei per month (63.36 lei per year) in the economic quality of life for each citizen. The government's policy of partial compensation for energy resources consumed by the population has a positive effect on the quality of life. Empirical studies have shown that unemployment, as well as energy vulnerability, negatively affect the quality of life, but the higher the share of the urban population and the share of the population with tertiary education, the greater the economic quality of life.

To reduce energy vulnerability and improve the quality of life of Moldovan citizens, two strategies need to be implemented in tandem. Firstly, because the country has significant, but untapped, potential for the development of green energy (solar and wind), it is necessary to simplify the regulatory framework to attract investors to this sector. Secondly, it is required to improve energy efficiency. For this purpose, it is necessary to replace outdated equipment and modernize buildings. But this also requires investment. Thirdly, it is needed to develop and promote building insulation programs with partial or complete subsidies for vulnerable groups of the population. Also, it is necessary to introduce social tariffs for the basic volume of energy consumption by the population, especially for the most vulnerable groups. Fourthly, it is required to conduct educational campaigns to inform about ways to reduce electricity and heat costs, and it is also necessary to train specialists in the field of energy audits, renewable energy sources, and building modernization.

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CONFLICT OF INTEREST.

Authors declare that they do not have any conflict of interest.

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