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STUDY REGARDING USING SOLAR ENERGY FOR HOUSEHOLD`S SUFFICIENCY AND RURAL COMMUNITIES DEVELOPMENT IN UKRAINE

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Abstract

The recent statistical data and market studies have shown that today Ukraine electricity market requires certain changes and modifications. Reform is necessary to build a new model of interaction between all participants in the energy market. The problem is too monopolized the electricity market, lack of understanding of the marketability of the category, transparency of electricity pricing, the ability to freely choose contractors and so on. Therefore, we can safely say that the new model of the energy market of Ukraine should be a powerful impetus to the energy sector development, which will lead to key indicators of sustainable economic development - energy efficiency, energy sufficiency, energy independent, use of renewable resources. This study surveyed households using solar photovoltaics to determine the prospects for solar energy in rural communities. Like methodology of research options for the development of alternative energy households, were considered traditional, technical and economic factors such as technological readiness and ability to pay, access to information and experience, if you want to implement sustainable energy solutions in rural communities. Were also identified factors that influence the household's decision to install a photovoltaic module. The survey asked about the demographic data of the respondent (gender, age and level of education) and household (household size, type of business and income) to find out their level of electricity needs. These findings indicate that the positive experience of rural users undoubtedly offers business opportunities to interact with rural households in meeting the unmet energy needs for further market growth.

Key words: *sustainable development, rural communities, renewable resources, solar energy, energy sufficiency, energy independent, households*

INTRODUCTION

Nearly two billion people in developing countries - one third of the world's population - do not have access to electricity. Firewood, agricultural residues, peat and animal traction continue to be the main energy resources for millions of rural families worldwide.

Finding alternative energy sources that are economical and environmentally friendly is crucial to increase agricultural productivity and improve the quality of life in rural communities. FAO's new Alternative Energy Development Program "Solar Photovoltaic Systems for Sustainable Agriculture and Rural Development", developed for the period 2020-2030, suggests that solar photovoltaic systems may be part of the solution [13]. Thus, ensuring the preservation and rational use of natural potential to ensure the stability of the socio-economic system poses a challenge to society to find ways to modernize the country's energy market (Fig.1).

At the same time, it is necessary to take into account the threats to the sustainability of energy supply of the national economy, which are barriers to achieving the goals of energy sustainability:

- Exhaustiveness fossil fuels;
- Maintaining and/or strengthening a critically high level of import dependence;
- High level of losses in the process of transportation and supply of energy resources;
- Rapid aging of energy infrastructure;
- low energy conversion efficiency and the appropriate level of environmental energy generation and related environmental degradation;

- Risks of reliability of energy resources supply due to lack of energy generating capacities;
- Further reduction in the relative competitiveness of domestic producers due to the high share of energy in production costs and the rising cost of traditional energy resources.

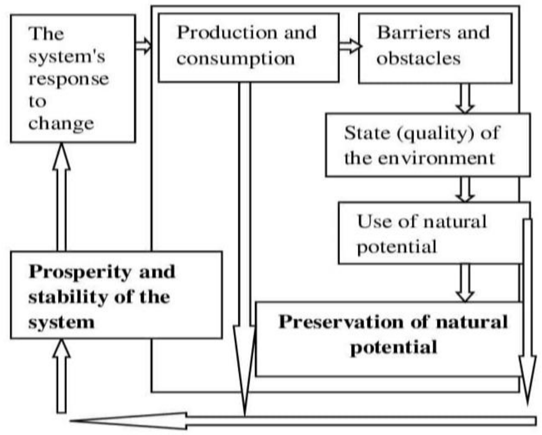

Fig.1. System diagram of energy sustainability goals
Source: Own deduction.

Distributed solar photovoltaic energy is a well-established technology to meet small rural energy needs in an affordable, reliable and carbon-neutral way [13]. These socio-technical transitions provide significant support to overcome energy poverty and act as a key tool for achieving well-being, economic prosperity and environmental protection provided for purposes of sustainable development.
This study surveyed households using solar photovoltaics to determine the prospects for solar energy in rural communities.
Factors affecting the desire to use more solar energy include income, education level, duration of solar energy, satisfaction, and time of day for electricity and public financial support procurement. This may explain the paradoxical aspects of subsidies, which are widely used as a social and political tool for improving the quality of life of those who are in financial trouble, but ignores the fundamental structural aspects of the energy system.
The world community has recognized that access to electricity is a first step and a prerequisite for socio-economic progress. Despite the fact that is passing the third decade of the XXI century, in rural areas of our country access to electricity is sometimes difficult and expensive. So, expanding the electricity grid costs a lot of money. For example, the expansion of the power grid in rural areas per 1 km costs from 65,000 to 150,000 UAH. Therefore, the use of solar energy in rural areas could become a cheaper and more environmentally friendly alternative [14]. Therefore, solar energy systems together with wind energy and other renewable energy sources are the only technically viable solution for delivering the energy needed to isolated rural communities. A small number of additional energy systems can significantly change the situation, making it possible to improve life in rural areas, increase agricultural productivity and create new opportunities for income. Solar energy is also more friendy for the environment. For example, indoor air pollution from burning non-renewable energy sources, such as wood and coal, kills more than 4 million people worldwide each year [13]. The majority of this population is poor and lives in rural areas, where the cost of expanding the network is high. Despite the price disadvantage (the installation of photovoltaic panels up to 5 kW costs $ 300, 15 kW - $ 500, more than 30 kW - $ 800-100), the benefits of solar energy in rural areas illustrate that the development of the solar technology is useful for areas that would not otherwise be able to access electricity. Thus, photovoltaic solar systems is still relatively expensive and therefore they are not a panacea for solving problems of poverty in rural areas. However, they offer a huge potential to fill certain extremely important points [13]. Currently, solar energy is used mainly for domestic lighting and household use. But the potential of solar energy is relatively untapped to increase agricultural productivity and rural development in general.
Recognizing energy inequality around the world, the UN Sustainable Development Goal (SDG) №7 seeks to provide affordable, reliable and clean energy to the population by 2030 [14].

The success of SDG № 7 lies in sustainable energy combinations, which are characterized by their multiscalarity and consist of two related but diverse elements, namely socio-technical systems involved in the integration of technology and innovation with society (supply factor) and energy equity, which is formed around the cost and risk of energy production and distribution (demand factor) [14]. SDG № 7 clearly provides complementarity of both socio-technical systems and social justice to promote sustainable energy supply to all segments of the population. To address energy poverty there are energy centers, linking production and consumption of energy and its distribution [17].

These intertwined technical and social aspects promote and enhance the current disproportionate and unequal distribution of power. For many, the failure of the principles of distributive justice in the energy sector is an insurmountable obstacle. Collectively, there is a disparity between generations and between segments of the population, which also limits the rights to energy and a clean environment, constrains social, economic and environmental conditions to break the cycle of energy poverty [11].

According to the Sustainable Development Goals, the use of solar energy has improved access to electricity in various developing countries and contributed to a 10% reduction in the global deficit of access to electricity over the past 15 years in the world [2].

In particular, India introduced a program of universal access to rural electrification and developed a National Action Plan on Climate Change, which aims is 40% production of total electricity from renewable sources by 2030 [6] to support rehabilitation climate activities.

Unreliable and highly subsidized electricity supply in rural areas is an unstable cycle when frequent interruptions and low wages lead to lower revenues and lower income restrain distribution companies to invest in rural infrastructure. Consequently, there is a need to modernize the electricity sector to destroy and break the existing carbon constraints and strengthen management systems to support the principles of justice and energy sustainable equitable economic growth [10].

From a socio-technical point of view, decentralized solar energy production is increasingly used as a viable alternative to solve existing problems of electrification of rural areas [15]. All over the world, decentralized electrification using solar photovoltaic programs is constantly used by governments and entrepreneurs to deploy electricity services in rural and remote communities in a cost-effective way [16]. At the regional level, solar photovoltaic energy (PV) is one of the most commonly used technologies for decentralized electrification of rural areas of Ukraine.

The main objective of this study is to understand the energy security of households, energy independence of solar energy sources, energy conservation and energy patriotism, which is generally consistent with the goals of sustainable development.

MATERIALS AND METHODS

For deeper understanding of current and future options for the development of alternative energy households, it should be considered traditional, technical and economic factors such as technological readiness and ability to pay, access to information and experience, if you want to implement sustainable energy solutions in rural communities [18]. Statistical data at the household level can provide detailed analysis that can help to understand the geographic, demographic and socio-economic conditions for solar energy development at the regional and national levels. There is little such data, as there is no public database on decentralized solar energy users (households).

To fill this gap, this study conducted a random selection of households in 7 districts of Sumy, Kharkiv, Poltava and Dnipropetrovsk regions as representatives of decentralized consumers of solar photovoltaic energy. 254 surveyed households were grouped into two categories: households that are only users of solar photovoltaic energy (PV) (110 households) and households that have both solar photovoltaic energy and connected to the energy grid (PV +) (144 households). Most households used solar energy only for residential purposes. Approximately 30% of these households also used electricity for small businesses (eg vegetable greenhouses, convenience stores, processing shops, repair shops, etc.).

Table 1. Description of decentralized use of solar photovoltaics in households

Indicator	Frequency	%
Total number of surveyed households	254	100
Type of electricity use - Solar only (PV) - Combined (solar and network) (PV +)	 110 144	 43.3 56.7
Type of photovoltaic equipment: - Household lighting; - Solar batteries up to 40 W; - Solar photovoltaic systems (40 W and above); - Solar power plant	 45 66 30 114	 17.6 26.0 11.7 44.7
Duration of use of PV: - Up to 1 year; - 1-3 years; - 3-5 years; - More than 5 years	 63 76 69 46	 24.8 29.9 27.2 18.1
Method of installing PV: - Within the grant (state, international) support program; - At their own expense, including credit	 51 203	 20.0 80.0

Source: Own research

Assessing the responses of households on the adequacy of their own needs depending on the type of electricity use (sufficient/insufficient), was performed a multiominal probit regression (logistics). Methods of logistic regression and discriminant analysis are used when it is necessary to clearly differentiate respondents by target categories. The groups are represented by levels of one single-parameter parameter. Differentiation is carried out in accordance with socio-demographic characteristics. These include, in particular, age, sex, number of hectares of land, income and others. In operations there are criteria for differentiation and variable. The latter encodes the target categories, which, in fact, should be divided into respondents.

Assume for each observation *t*, the net utility gained from the consumption of energy sufficiency U_t, which is not observable, is related to a set of exogenous variables x_t (I×1 vector, where *I* is the total number of exogenous variables). Then, we are interested in coefficients β, which describe this relationship in the following latent model (as well as in the related probit model), assuming error term μ_t follows a standard normal distribution $\mu_t \sim N(0,1)$ [7]:

$$U_t = x'_t\beta + \mu_t$$

Thist model is equivalent to the probit model

$$y_t = x'_t\beta + \mu_t,$$

when the relationship between latent utility variable U_t and the observable response (0/1) variable of whether a household purchases energy sufficiency, y_t, satisfies:

$$Y_t = \begin{cases} 1 \; if \; U_t > 0 \\ 0 \; otherwise \end{cases}$$

Note that in the above model, the *j-th* element of coefficients vector β, β_j ($j \in \{1,2,\ldots, I\}$) measures the change in the conditional probability Pr ($y_t = 1|x_t$) when there is unit change in x^j_t (j-th element in vector x_t). To further develop this regression model, in addition to i.i.d normally distributed error terms, we assume that the conditional probability takes the normal form:

$$Pr(y_t=1|x_t)=\Phi(x'_t\beta),$$

where: Φ(.) is the standard normal CDF.
A standard statistical textbook such as Greene (2011) would show that the estimator β could be calculated through maximizing the following log-likelihood function ln£(β) [4]:

$$\beta=\text{argmax}\beta[\ln£(\beta)]=\text{argmax}\beta[(1-y_t)\ln(1-\Phi(x'_t\beta)))]$$

In order to report standard regression outcomes such as t-statistic, p-value, we need the estimated co-variance matrix of the estimator β, i.e., V_β, which is based on the

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inverse Hessian matrix according to Greene (2011),

$$V_{\beta}=(H)^{-}1$$

where: H=∇2ln£(β) is the estimated Hessian of the log-likelihood function ln£(β) at the solution point β.
GAMS (General Algebraic Modeling System) provides a mechanism for generating a Hessen matrix *H* at the solution point. We used a discrete selection model in GAMS, the results of which are recorded in NEOS Server.

RESULTS AND DISCUSSIONS

Table 2 shows the level of satisfaction reported by participants compared to the previous power supply used in households. A high level of satisfaction was recorded among rural consumers of solar energy. Customer satisfaction was extremely high in households using only solar energy (PV). For this group, more than 67% of participants (compared to 76% of PV + households) rated solar energy better than previously used light sources, in which case respondents reported power outages through the central grid.

Table 2. Household satisfaction of solar photovoltaic power compared to previous power supply

Level of satisfaction	Total amount (254)		PV (110)		PV + (144)	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Below expectations	25	9.8	16	14.5	9	6.3
At the level of the previous source	45	17.7	20	18.2	25	17.4
Above expectations	184	72.5	74	67.3	110	76.3

Source: Own calculation

The level of satisfaction was checked by six variables: safety, total productivity, battery life, equipment quality, maintenance support and access to the electricity grid (Fig. 2).

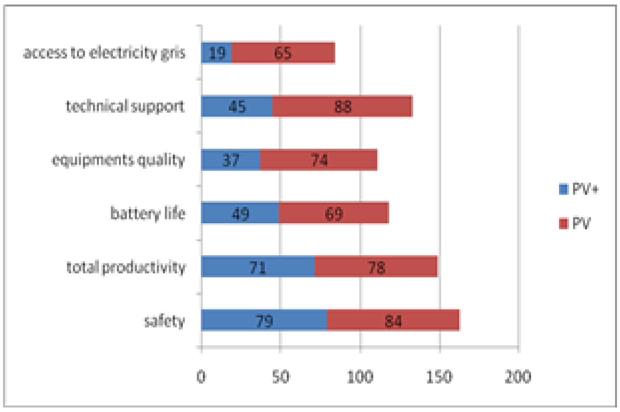

Fig. 2. Estimation of households using solar energy
Source: Own calculation.

Households reported high levels of satisfaction in all six aspects, although some households had lower views on service levels. Satisfaction with the comparison of household types (PV and PV +) also showed similar trends (Fig. 3), when households that use only solar energy were more satisfied than used solar energy in addition to the grid.

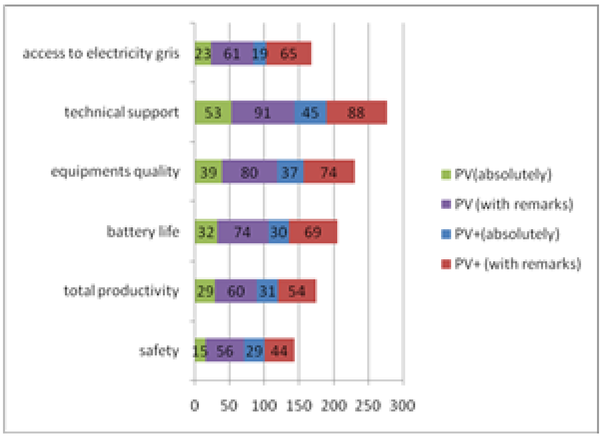

Fig.3. The level of satisfaction households using solar energy
Source: Own calculation

These findings indicate that the positive experience of rural users undoubtedly offers business opportunities to interact with rural households in meeting the unmet energy needs for further market growth.
We found that satisfied households likely will want more solar energy. In other words, changing the satisfaction of households by 1% increases commitment to solar energy by 0.16% (correlation coefficient of 0.161 with a standard error of 0.0186).

Table 3. Consolidated portrait of households using solar energy

Indicator	Total amount (254)		PV (110)		PV + (144)	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Sex						
- Male	189	74.4	100	90.9	89	61.8
- Female	65	25.6	10	9.1	55	38.2
Age						
- 18-25	9	3.5	3	2.7	6	4.2
- 26-32	36	14.2	17	15.5	19	13.2
- 33-40	89	35.0	27	24.5	62	43.1
- 41-55	97	38.2	54	49.1	43	29.9
- 56 and more	23	9.1	9	8.2	14	9.7
Educational level						
- Secondary	16	6.3	9	8.2	7	4.9
- Professional and technical	97	38.2	54	49.1	43	29.9
- Bachelor	89	35.0	19	17.3	70	48.6
- Master	52	20.5	28	25.5	24	16.7
Type of business						
- None	42	16.5	11	10.0	31	21.5
- Agricultural production	182	71.7	78	70.9	104	72.2
- Service and trade	30	11.8	21	19.1	9	6.3
The size of the farm						
- Up to 3 hectares	51	20.1	19	17.3	32	22.2
- 3-5 ha	176	69.3	76	69.1	100	69.4
- More than 5 hectares	27	10.6	15	13.6	12	8.3
Average annual income per 1 household member, UAH						
- Up to 50,000	65	25.6	26	23.6	39	27.1
- 50,000-200,000	119	46.9	68	61.2	51	35.4
- Over 200,000	70	27.5	16	15.2	54	37.5

Source: Own calculation.

We also identified factors that influence the household's decision to install a photovoltaic module. The survey asked about the demographic data of the respondent (gender, age and level of education) and household (household size, type of business and income) to find out their level of electricity needs. Table 3 summarizes the statistics of households that participated in the survey and use solar photovoltaic energy.

Using a multinomial probit-regression model, the effect of these determinants was evaluated independently of each other and their combined effect in predicting the probability of households seeking to establish a source of solar energy generation. First, consider the coefficients at the output of the probit regression in Table 4.

Table 4. The results of the multinomial probit regression model

Indicator	Binary value	Coef.	SE
Sex	yes	0.528	0.298
	no	-0.144	0.366
Age	yes	0.388	0.116
	no	-0.258	0.124
Educational level	yes	0.777	0.097
	no	-0.631	0.084
Type of business	yes	-0.341	0.131
	no	-0.122	0.088
Size of household	yes	0.544	0.011
	no	-0.280	0.177
Average annual income per 1 household member, UAH	yes	0.772	0.136
	no	-0.762	0.152

Source: Own calculation.

By interpreting the marginal effects (Table 5) of the previously identified impact factors, was estimated the probability of the dependent variable with respect to the predictor variables, keeping all other predictors constant at the same values. Respondents were asked to choose one of three possible answers (no, maybe / indefinitely, yes), which were presented as a dependent variable. Thus, evaluating individual determinants, it was found that annual income, level of education, significantly influenced on the desire to install solar energy in households, thus ensuring their own energy adequacy and energy independence. Factors such as age, gender, and type of business did not significantly influence on the decisions about the use of solar generators.

Thus, by interpreting the obtained indicators, it was found that, for example, people with higher education (master and bachelor) and an average annual income of up to UAH 200,000 per 1 household member are 13% more likely to install solar generators than people with technical education.

Table 5. The marginal effects of impact factors on the level of satisfaction households

indicator	Variable variation	dy/dx	Std. Err.
Sex	yes	0.324	0.011
	maybe / indefinitely	0.0961	0.026
	no	-0.0441	0.030
Age	yes	0.261	0.077
	maybe / indefinitely	0.319	0.013
	no	-0.0811	0.044
Educational level	yes	0.014	0.031
	maybe / indefinitely	0.239	0.063
	no	-0.101	0.019
Type of business	yes	0.0891	0.022
	maybe / indefinitely	-0.0145	0.056
	no	-0.127	0.048
Size of household	yes	0.0124	0.092
	maybe / indefinitely	0.189	0.016
	no	-0.1711	0.042
Average annual income per 1 household member, UAH	yes	0.0638	0.039
	maybe / indefinitely	-0.0181	0.057
	no	-0.1112	0.038

Source: Own calculation

The service life and the level of service of photovoltaic equipment are one of the problematic issues due to which the respondents lowered the assessment of the level of satisfaction. This becomes a constraint on people's willingness to purchase solar photovoltaic modules if there is another alternative energy [8, 13].

After review with respondents were also found that households that received their photovoltaic system under a grant (free of charge) were less likely to want more capacity than those who paid for their system in full value or those who received a partial subsidy to support them. Also notable in this analysis is that households receiving monthly fee for green tariff for excess energy produced, tended much to increase the number of photovoltaic modules, for not only feel their own energy sufficiency and independence, but also found an additional source of income [5].

CONCLUSIONS

Energy sufficiency, energy independence and environmental sustainability are equally important for achieving the goals of sustainable development and improving the well-being of the population. It is because of environmental friendliness and human health safety, the solar photovoltaic systems, so-called clean technologies, are gaining more and more popularity among consumers. In addition, they offer a reliable solution to overcome the cycle of energy independence and increase the level of energy patriotism.

Compared to fossil fuel energy, solar energy systems are flexible, maintenance-free and environmentally friendly, but they have their limitations. Thus, batteries for storing solar electricity can be expensive and problematic in service.

However, the most problematic in our country are institutional barriers: high start-up costs combined with a lack of funding mechanisms that lead to low sales, also and a relatively long chain from the solar panel manufacturer to the final consumer leads to high transaction costs. These are key reasons for the lack of infrastructure and political commitment. This vicious cycle usually makes solar energy systems unattractive for rural consumers, and for many investors.

Taking into account the existing political, social and economic realities in Ukraine, it is important to first achieve political and institutional sufficiency in the economic development of energy sources. The introduction of new technologies must comply with the principles of social justice in order to meet the energy needs of households that are making significant initial investments in their own energy independence.

To alleviate the conditions for making such a decision, it is advisable to refer to the world experience of energy cooperatives in the united territorial communities. Such organizations not only stimulate the transition to renewable sources, but also allow the use of local resources and work for the benefit of the community.

This organizational system, becoming an important element of decentralization, offers several advantages. First of all, the cooperative allows you to build the necessary infrastructure without attracting foreign investors or expensive loans. This is usually not possible for individuals or small companies.

In addition, such system reduces community dependence on large energy companies and fossil fuels that may rise in price. Using local resources help to save energy and sell excess renewable electricity by a "green" tariff". In addition, energy cooperatives are more environmentally friendly: the community switch to renewable energy sources, use local resources (such as agricultural waste) and reduce the need to transport energy.

But there is hope for overcoming financial and institutional barriers to the success of solar energy. Connecting rural communities to alternative energy networks require significant government subsidies and does not always bring the projected benefits. But here it should be remembered that rural economic and social development depends on the successful implementation of energy independence projects, and not vice versa.

REFERENCES

[1]BNEF & World Bank, 2016, Off-grid Solar Market Trend Report, http://www.energynet.co.uk/webfm_send/1690, Accessed on Jan. 27, 2021.

[2]Geels, F.W., 2002, Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study, Resource Policy, Vol.31: 1257-1274.

[3]Gill, B., Gupta, A., Palit, D., 2019, Rural Electrification: Impact on Distribution Companies, The Energy and Resource Institute, New Delhi, pp. 189-193.

[4]Greene, W., 2011, Econometrics Analysis, 7th ed. Prentice Hall, Upper Saddle River, NJ., pp. 307-316.

[5]GOGLA and the World Bank Group, 2018, Global off-grid solar market trends report, https://www.gogla.org/publications, Accessed on 31st Jan 2021.

[6]Hirmer, S., Cruickshank, H., 2014, The user-value of rural electrification: an analysis and adoption of existing models and theories, Renewable Sustainable Energy, Vol.34: 145-154.

[7]McCulloch, R., Rossi, P.E., 1994, An exact likelihood analysis of the multinomial probit model, Economics, Vol.64: 207-240.

[8]Ministry of Environment, Forest and Climate Change (MoEFCC), 2008, National Action Plan on Climate Change,http://www.moef.nic.in/ccd-napcc, Accessed on Jan. 29, 2021.

[9]Palit, D., 2013, Solar energy programs for rural electrification: experiences and lessons from South Asia Energy Sustainable Development, Vol.17:270-279.

[10]Sareen, S., Haarstad, H., 2018, Bridging socio-technical and justice aspects of sustainable energy transitions, Applied Energy, Vol. 228:624-632.

[11]Riva, F., Ahlborg, H., Hartvigsson, E., Pachauri, S., Colombo, E., 2018, Electricity access and rural development: review of complex socio-economic dynamics and causal diagrams for more appropriate energy modeling, Energy Sustainable Development, Vol.43:203-223.

[12]Simcock, N., Mullen, C., 2016, Energy demand for everyday mobility and domestic life: exploring the justice implications, Energy Resources and Social Sciences, Vol.18:1-6.

[13]Sovacool, B.K., Burke, M., Baker, L., Kotikalapudi, C.K., Wlokas, H., 2017, New frontiers and conceptual frameworks for energy justice, Energy Policy, Vol.105: 677-691

[14]Sovacool, B.K., 2012, The political economy of energy poverty: a review of key challenges Energy Sustainable Development, Vol.16: 272-282.

[15]Sovacool, B.K., Dworkin, M.H., 2014, Global Energy Justice: Problems, Principles, and Practices, Cambridge Cambridge University Press, pp.307-309.

[16]Sovacool, B.K., Heffron, R.J., McCauley, D., Goldthau, A., 2016, Energy decisions reframed as justice and ethical concerns, Natural Energy, Vol.1:1624-1629.

[17]United Nations, 2015, Sustainable Development Goals, https://sustainabledevelopment.un.org/sdgs, Accessed on Jan.30, 2021.

[18]United Nations Statistics Division, 2018, The Sustainable Development Goals Report, Department of Economic and Social Affairs, United Nations, New York, https://unstats.un.org/sdgs/report/2018, Accessed on Jan 31, 2021.