

Measure of structural change in the household energy mix – stuck in a traditional biomass trap?

Tekla Szép associate professor

Zoltán Nagy associate professor

Katalin Lipták associate professor

Institute of World and Regional Economics, University of Miskolc
Miskolc, Hungary

Abstract—Improving energy efficiency and renewable energy sources are key in the energy transition. However, not only the share of renewables, but the energy mix also has an important role to play. Traditional biomass must be distinguished from modern renewables and the traditional biomass trap must be avoided. Fuel switching is not a simple task, the theories of energy ladder and energy stacking are used to highlight it. The study aims to measure the degree of change in the household energy mix. The Moore, NAV and the modified LILIEN indices are applied. The results show that the progress of the sustainable energy transition is measurable, but its' degree is stagnating or even declining in the household sector of the EU. In most CEE countries, the households are stuck in the so-called traditional biomass trap. Energy strategies should make it a priority to break out of this trap by promoting a shift from traditional firewood to more modern and cleaner renewable energy sources.

Index Terms-- structural change index, biomass, firewood, energy transition, household sector.

I. INTRODUCTION

The Russia-Ukraine war that started on 24 February 2022 has challenged the European Union. The pillars of the well-known energy trilemma have been rearranged, with energy security taking priority over environmental sustainability and, in many respects, prices becoming secondary, with security of supply (i.e., having energy at all) becoming the primary objective.

In less than a quarter of a year, the European Commission presented the REPowerEU plan to the European Parliament in May 2022. It aims to drastically reduce Russia's energy dependence and accelerate the green energy transition. What does this mean? To sum up: improving energy efficiency, saving energy, increasing the share of renewable energy sources and diversifying sources of supply. In fact, the objectives that have been at the heart of the energy discourse for decades are reappearing - in a more pronounced form. The plan is very ambitious, particularly in terms of speeding up the energy transition. It is important to know that energy transitions have accompanied human history and have often spanned decades. The current so-called 'green energy transition' (i.e., the

shift from fossil fuels to renewable energy sources) can be shaped and even accelerated with the right policies and targeted support.

Improving energy efficiency and renewable energy sources are key to achieving carbon neutrality and the energy transition. However, in addition to the share of renewables in final energy consumption, the energy mix also has a significant role to play. Traditional biomass must be distinguished from modern renewables in all cases. The sustainable energy transition must be based on the latter if the firewood trap is to be avoided. On the social side, the use of conventional biomass is closely linked to energy poverty, which is no longer a problem only for the lowest income deciles as a result of the energy crisis of 2021-2022. Fuel switching is not a simple task. In this study, we use the theory of energy and fuel storage to illustrate the process and to highlight the factors that could further slowdown the energy transition.

The rest of the paper is organized as follows. Section II. presents the theoretical background of the analysis, namely the energy ladder and energy stacking theory. Section III. (data and methodology) introduces the applied data (databases) and the structural change indexes. Section IV. shows the results, including our main findings on the change of the national and household energy mix. Finally in Section V., the paper offers conclusions and policy implications.

II. THEORETICAL BACKGROUND

A. Energy ladder and energy stacking theory

To understand the conventional biomass trap, the theory of energy and fuel storage is used as a starting point. According to the energy ladder theory (Figure 1), the energy transition in the household sector is a linear and one-way process, whereby households gradually shift from lower-quality, more polluting energy sources (e.g. firewood, coal, coke) to cleaner, more advanced energy sources as a result of increasing income and human welfare [1], [2]. The 4A concept of fuel availability, affordability, accessibility, acceptability [3] plays an important role in this fuel choice. As one moves up the energy ladder, welfare increases (and vice versa). This is closely related to the

consumption theory that as income increases, not only do we consume more, but the quality of the products we consume also improves. The theory assumes that households use one type of energy carrier for one activity. For example, if they switch from using firewood for heating to natural gas, this is considered to be permanent and excludes the parallel use of different energy sources.

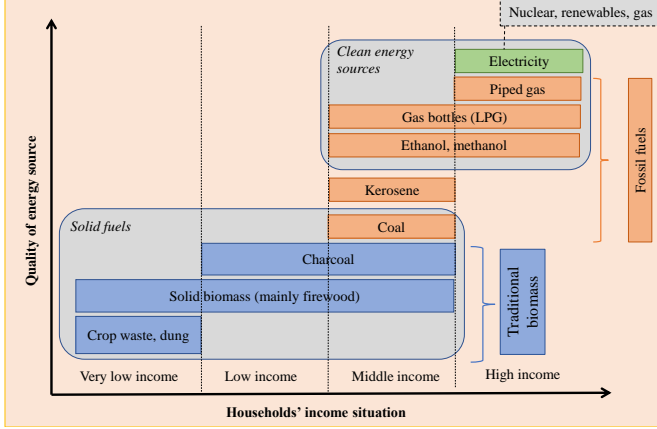


Figure 1: Energy ladder theory

Source: own compilation based on [4], [5]

However, it fails to consider that households can easily switch between different energy sources, moving up and down the ladder as prices, incomes and other preferences change. Socio-cultural backgrounds in energy consumption patterns (e.g. cooking techniques) also provide important explanations for understanding the process of energy transition [6]. In many cases, the heating appliances themselves allow for the simultaneous use of multiple fuels (mixed fuel boilers, coal, and wood), leading to the theory of energy stacking. According to this theory, households will only partially switch to other, cleaner fuels while retaining older, more polluting sources [6]. In other words, households are not expected to completely abandon lower quality fuels, and complete fuel switching is very rare. More likely is the parallel use of different fuels (although the proportions may of course vary), which will slow down the energy transition.

III. DATA AND METHODOLOGY

A. Structural Change Indexes

A number of indicators can be used to measure structural change, including Moore index (the degree of industrial structure upgrading), the NAV index (norm of absolute values, also known as Michaely or Stoikov index), the LILIEN and the modified LILIEN index (MLI index) [7].

The Moore index measures the degree of structural change. The index (Eq. 2) was developed by [8] and it is “based on the fact that the structure of output in any period can be described by a vector whose coordinates are the quantities of outputs which form the basis for calculating the index numbers” [7], [8, p. 106], [9], [10].

$$M_t^+ = \sum_{i=1}^n W_{i,t} * W_{i,t+1} / \left[\left(\sum_{i=1}^n W_{i,t}^2 \right)^{1/2} * \left(\sum_{i=1}^n W_{i,t+1}^2 \right)^{1/2} \right] \quad (1)$$

where M_t^+ is the Moore value of structural change; $W_{i,t}$ is the share of fuels in final energy consumption of the household sector (i = solid fossil fuels, oil and petroleum products, natural gas, electricity, heat, renewables and biofuels and other fuels) in t period; $W_{i,t+1}$ is the share of fuels in final energy consumption of the household sector in $t+1$ period.

The change in the energy mix is shown by the cosine of the angle between vectors $\cos \alpha = M_t^+$, $\alpha = \arccos M_t^+$. The higher the α , the higher the rate of the change in the energy mix. The unit of measure is degree.

The formula of the NAV index based on [11], [12] is the following:

$$NAV = \frac{1}{2} \sum_{i=1}^n |W_{i,t+1} - W_{i,t}| \quad (2)$$

The modified Lilien index (MLI) based on Dietrich (2012) is:

$$MLI = \sqrt{\sum_{i=1}^n W_{i,t} * W_{i,t+1} * \left[\ln \frac{W_{i,t+1}}{W_{i,t}} \right]^2}, W_{i,t} > 0, W_{i,t+1} > 0. \quad (3)$$

All three indices can take values between 0 and 1. The closer the value is to 1, the more intense the restructuring. For example, if any index is 0.1, it means that 10% of energy resources have been affected by reallocation.

For the calculation, we used data on final energy consumption (toe) and final energy consumption in the household sector (toe) broken down into solid fossil fuels, oil and petroleum products, natural gas, electricity, heat, renewables and biofuels and other fuels. Data source is Eurostat [13], the examined time period is 2000-2020.

In this study, we will refer to primary solid biomass as biomass for simplicity and, following the methodology of [14], we distinguish between two main types, i.e. traditional (e.g. firewood) and modern (e.g. pellets) biomass (based on end-use and combustion). Solid fossil fuels are defined as coal and other products made from coal according to [15].

IV. RESULTS

The energy mix in the EU is changing at an accelerating or decelerating pace, which leads to conclusions on the energy transition. The results of the Moore, NAV and MLI indices are mutually reinforcing and (with one or two exceptions) do not show any contradictions.

TABLE I. CHANGES OF THE NATIONAL ENERGY MIX (MOORE, NAV AND MLI INDEX) BETWEEN 2000 AND 2020, 5-YEARS PERIODS – RESULTS OF STRUCTURAL CHANGE INDICES

	2001-2005			2006-2010			2011-2015			2016-2020		
	Moore	NAV	MLI	Moore	NAV	MLI	Moore	NAV	MLI	Moore	NAV	MLI
EU-27	2.438	0.027	0.024	4.494	0.037	0.044	2.241	0.021	0.02	3.38	0.027	0.031
BE	1.468	0.015	0.014	4.076	0.04	0.043	1.757	0.017	0.017	5.377	0.048	0.053
DK	2.135	0.021	0.021	5.574	0.055	0.054	3.923	0.036	0.036	2.362	0.02	0.022
DE	5.623	0.060	0.061	4.844	0.039	0.049	1.737	0.016	0.015	3.496	0.033	0.031
IE	1.037	0.015	0.013	4.251	0.056	0.059	4.17	0.047	0.055	3.603	0.04	0.04
GR	2.623	0.033	0.033	4.368	0.058	0.064	6.356	0.08	0.089	3.766	0.043	0.046
ES	4.197	0.044	0.049	4.087	0.048	0.046	3.171	0.031	0.036	3.748	0.036	0.042
FR	3.646	0.035	0.038	4.911	0.047	0.049	1.972	0.02	0.018	3.767	0.033	0.037
HR	1.952	0.019	0.021	3.719	0.031	0.036	4.145	0.04	0.038	3.471	0.035	0.035
LU	5.213	0.074	0.070	3.259	0.046	0.051	1.539	0.021	0.02	3.753	0.053	0.059
MT	0.418	0.004	0.005	3.429	0.034	0.042	1.751	0.02	0.026	5.233	0.055	0.07
NL	2.951	0.026	0.030	2.652	0.025	0.027	4.808	0.049	0.048	3.153	0.034	0.031
AT	2.569	0.026	0.027	7.967	0.067	0.078	2.317	0.021	0.021	2.171	0.019	0.019
PT	4.778	0.062	0.054	5.907	0.062	0.072	5.375	0.051	0.058	3.543	0.033	0.037
SI	3.165	0.035	0.033	2.146	0.024	0.023	4.211	0.038	0.043	4.008	0.038	0.041
SK	8.281	0.089	0.074	5.513	0.05	0.05	9.716	0.09	0.079	9.159	0.084	0.071
SE	5.983	0.056	0.056	6.15	0.055	0.057	9.848	0.074	0.087	7.905	0.057	0.07
BG	4.272	0.038	0.036	8.262	0.086	0.068	4.864	0.043	0.041	5.231	0.049	0.046
CZ	10.296	0.072	0.078	6.239	0.042	0.048	6.723	0.058	0.052	3.185	0.024	0.024
EE	4.903	0.047	0.040	6.248	0.057	0.051	5.988	0.054	0.052	3.482	0.034	0.029
IT	3.688	0.044	0.040	6.591	0.061	0.069	2.396	0.022	0.023	6.813	0.056	0.064
CY	3.286	0.039	0.052	4.462	0.063	0.067	1.902	0.026	0.025	7.274	0.086	0.108
LV	5.131	0.033	0.043	3.396	0.033	0.028	5.879	0.057	0.05	1.778	0.017	0.015
LT	5.341	0.053	0.047	1.405	0.013	0.013	6.892	0.062	0.06	4.677	0.036	0.044
HU	3.268	0.031	0.031	8.972	0.081	0.085	7.194	0.06	0.062	2.739	0.024	0.025
PL	5.071	0.043	0.039	2.754	0.02	0.021	4.969	0.039	0.038	9.584	0.079	0.076
RO	9.955	0.072	0.080	8.083	0.068	0.065	6.984	0.064	0.057	3.693	0.036	0.033
FI	3.293	0.029	0.028	4.931	0.04	0.042	5.684	0.046	0.048	5.385	0.042	0.046

Note: red - slowing change, green - accelerating change compared to the previous 5-year period

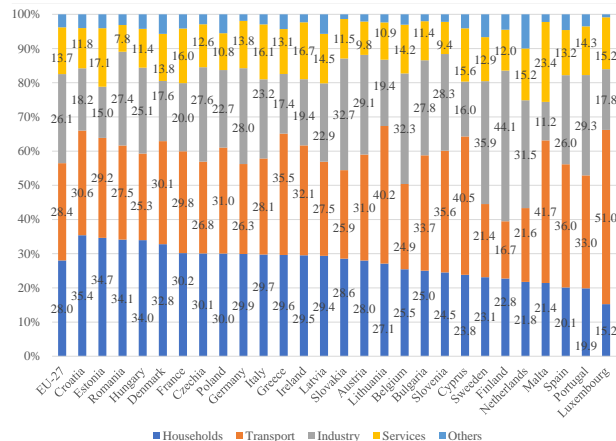


Figure 1: Final energy consumption by sector in the European Union (% , 2020)

We break the results down into 5-year periods, always comparing each period with the previous one (chaining the results) (Table I. and II.). In the European Union, the period 2006-2010 and the period 2016-2020 show a rather accelerating trend compared to the previous 5 years. However, at Member State level, the period 2016-2020 is much more controversial. In 17 Member States, the results point to a slowdown in energy transition, confirming what was described earlier. In other

words, the transition from fossil to renewable energy sources will take a long time, the energy mix is very rigid and changes only slowly (Table I.).

In the following, we will limit the analysis to the household sector. In terms of final energy consumption by sector, we still see that both in the EU and in the CEE region, the household and transport sectors are still the most important, followed by industry (Figure 2).

If we look at the speed of energy transition in the household sector, the slowdown is even more striking: between 2011 and 2015, energy transition accelerated in only 7 Member States, and between 2016 and 2020 in 10. This indirectly highlights the inadequacy of support and incentive schemes.

TABLE II. CHANGES OF THE HOUSEHOLD ENERGY MIX (MOORE, NAV AND MLI INDEX) BETWEEN 2000 AND 2020, 5-YEARS PERIODS – RESULTS OF STRUCTURAL CHANGE INDICES

	2001-2005			2006-2010			2011-2015			2016-2020		
	Moore	NAV	MLI	Moore	NAV	MLI	Moore	NAV	MLI	Moore	NAV	MLI
EU-27	3.795	0.033	0.031	7.734	0.054	0.063	4.415	0.039	0.036	1.965	0.019	0.017
BE	4.967	0.046	0.052	9.514	0.081	0.097	3.564	0.031	0.036	1.475	0.015	0.014
DK	8.722	0.056	0.072	7.95	0.07	0.069	7.022	0.059	0.062	3.069	0.025	0.027
DE	4.345	0.040	0.039	7.783	0.061	0.069	3.181	0.031	0.028	2.684	0.027	0.025
IE	5.298	0.057	0.054	2.269	0.024	0.021	7.945	0.068	0.08	5.696	0.053	0.059
GR	4.044	0.044	0.046	14.449	0.142	0.166	11.418	0.093	0.115	4.18	0.037	0.04
ES	9.894	0.090	0.089	11.112	0.09	0.101	5.1	0.041	0.047	5.985	0.059	0.059
FR	3.340	0.029	0.031	8.951	0.086	0.076	5.406	0.047	0.049	4.642	0.043	0.042
HR	3.654	0.033	0.034	4.572	0.042	0.044	6.043	0.065	0.067	4.29	0.04	0.043
LU	6.468	0.053	0.068	8.337	0.066	0.088	4.163	0.044	0.047	10.467	0.086	0.113
MT	11.623	0.116	0.163	5.747	0.062	0.054	1.823	0.025	0.031	7.256	0.073	0.093
NL	1.510	0.024	0.027	1.371	0.017	0.021	4.607	0.065	0.08	2.786	0.035	0.044
AT	9.534	0.072	0.076	8.902	0.066	0.072	6.495	0.057	0.053	2.474	0.021	0.02
PT	8.112	0.083	0.080	14.529	0.117	0.139	15.508	0.123	0.149	2.037	0.018	0.02
SI	4.274	0.036	0.040	7.365	0.06	0.067	12.028	0.103	0.118	8.368	0.069	0.083
SK	9.690	0.103	0.119	3.515	0.034	0.039	6.718	0.071	0.076	24.4	0.224	0.212
SE	4.989	0.044	0.052	7.722	0.066	0.085	7.12	0.069	0.077	0.885	0.01	0.012
BG	7.565	0.066	0.036	7.813	0.081	0.075	2.982	0.031	0.031	4.244	0.046	0.042
CZ	6.500	0.058	0.078	5.859	0.053	0.05	10.761	0.077	0.088	6.647	0.052	0.057
EE	4.155	0.045	0.040	11.458	0.097	0.113	2.1	0.02	0.021	1.063	0.011	0.01
IT	8.856	0.084	0.040	10.577	0.089	0.111	3.156	0.031	0.031	1.631	0.015	0.017
CY	13.408	0.128	0.052	14.226	0.129	0.158	6.252	0.05	0.067	7.813	0.065	0.08
LV	4.183	0.041	0.043	7.568	0.081	0.091	2.511	0.024	0.025	1.835	0.019	0.016
LT	2.959	0.033	0.047	3.574	0.043	0.036	3.731	0.03	0.034	5.034	0.053	0.048
HU	5.215	0.061	0.031	11.802	0.108	0.125	8.124	0.072	0.081	10.471	0.087	0.107
PL	10.537	0.071	0.039	6.281	0.047	0.055	4.783	0.041	0.042	16.927	0.119	0.134
RO	16.255	0.129	0.080	12.206	0.115	0.119	6.458	0.068	0.062	5.036	0.044	0.048
FI	3.500	0.027	0.028	5.075	0.044	0.047	3.925	0.037	0.04	8.396	0.067	0.08

Note: red - slowing change, green - accelerating change compared to the previous 5-year period

It is worth identifying intervention points in the implementation of the energy transition. For the household sector, this is clearly residential heating, which still accounted for 62.8% of residential energy use in the EU in 2020. As illustrated in Figure 3, there are significant differences between Member States in terms of residential energy use per m² for heating. In Hungary, for example, the energy demand of buildings is 55.4% higher than the EU average, due to its low energy performance. This highlights the outstanding energy efficiency potential of our buildings.

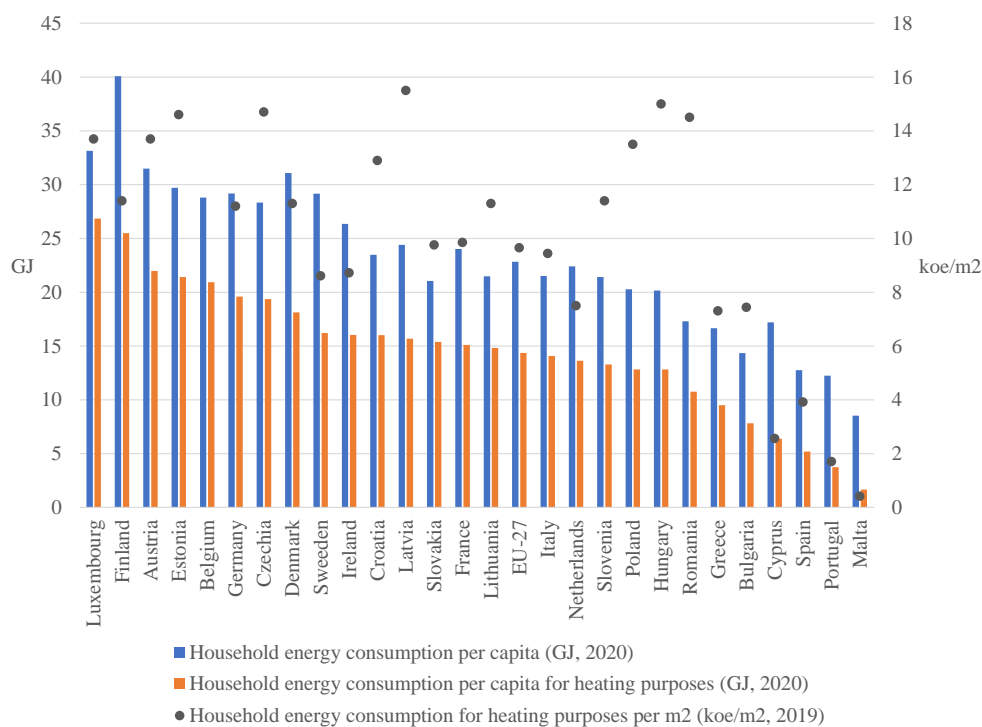


Figure 3: Household energy consumption per capita and household energy consumption per capita for heating purposes (EU-27, 2020, GJ), and household energy consumption for heating purposes per m² (koe/m², 2019)

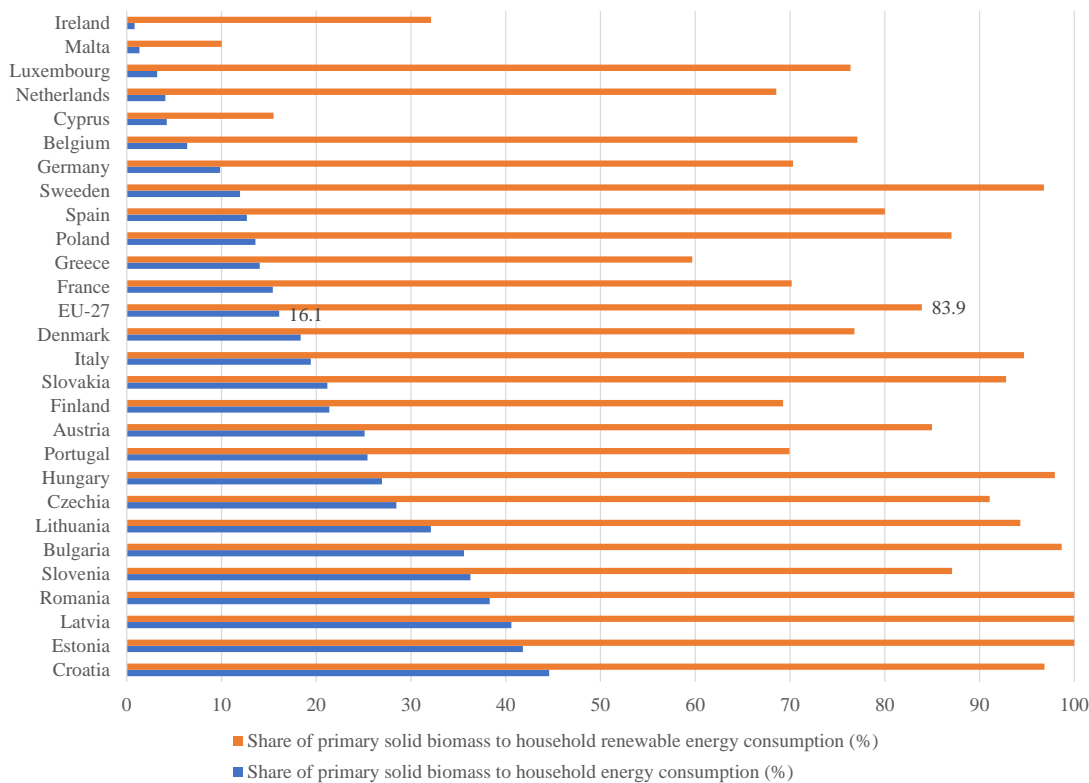


Figure 4: Share of primary solid biomass to household energy consumption (EU-27, 2020, %)

Let's now look at the residential energy mix. In the European Union, primary solid biomass accounted for 16.1% of household energy use and 83.9% of household renewable

energy use (Figure 4). In other words, the share of renewable energy sources in the household sector is still predominantly biomass, while the share of modern renewable energy sources

(and the devices that enable their use, such as heat pumps, solar panels, solar collectors) is particularly low. These figures are even worse in CEE households. In several countries (e.g., Hungary, Bulgaria, Romania, Latvia, Estonia), the share of biomass in household renewable energy use is close to 100%.

V. CONCLUSION

It can be concluded that no rapid energy transition is expected in the household sector. One of the main reasons for this is energy stacking. According to the energy ladder theory the energy transition in the household sector is a linear and unidirectional process. Households renovate their properties, carry out necessary insulation, window replacements, they modernize their heating systems as a result of rising income and human welfare. At the end the energy efficiency of buildings improves. The households are switching from the much more polluting energy sources of the past to cleaner, more modern solutions. But the reality is more nuanced than that, and more realistically, it is a two-way process. In other words, households are moving up and down the ladder, and in many cases using multiple energy sources for the same household activity.

However, the simultaneous use of different energy carriers slows down the energy transition. In several countries in the CEE region, this is exactly what we see, confirming the energy stacking theory. According to it, the disappearance of firewood for household heating cannot be guaranteed. There is a serious risk of being stuck in a so-called firewood trap, especially for energy-poor households. Member States with high energy intensity, a high share of fossil fuels in both the household and national energy mix and with a lower standard of living (lower disposable income) should prioritize energy sustainability.

ACKNOWLEDGMENT

„This project is funded by the European Union’s Horizon Europe programme under grant agreement No. 101079354.”

REFERENCES

- [1] H. Han, S. Wu, and Z. Zhang, “Factors underlying rural household energy transition: A case study of China,” *Energy Policy*, vol. 114, pp. 234–244, Mar. 2018, doi: 10.1016/j.enpol.2017.11.052.
- [2] S. Wang, Y. Liu, C. Zhao, and H. Pu, “Residential energy consumption and its linkages with life expectancy in mainland China: A geographically weighted regression approach and energy-ladder-based perspective,” *Energy*, vol. 177, pp. 347–357, Jun. 2019, doi: 10.1016/j.energy.2019.04.099.
- [3] R. Kowsari and H. Zerriffi, “Three dimensional energy profile:,” *Energy Policy*, vol. 39, no. 12, pp. 7505–7517, 2011.
- [4] M. Roser, “The ‘Energy Ladder’: What energy sources do people on different incomes rely on?,” *Our World in Data*, 2021. <https://ourworldindata.org/energy-ladder> (accessed Dec. 07, 2022).
- [5] WHO, “Fuel for life: household energy and health,” 2006. Accessed: Dec. 07, 2022. [Online]. Available: <https://www.who.int/publications-detail-redirect/9789241563161>
- [6] P. Yadav, P. J. Davies, and S. Asumadu-Sarkodie, “Fuel choice and tradition: Why fuel stacking and the energy ladder are out of step?,” *Solar Energy*, vol. 214, pp. 491–501, Jan. 2021, doi: 10.1016/j.solener.2020.11.077.
- [7] T. S. Szép, “Az energia gazdasági szerepének vizsgálata Kelet-Közép-Európában, 1990 és 2009 között,” in *Disszertáció*, Miskolc, 2013, p. 244. doi: 10.14750/ME.2013.035.
- [8] J. H. Moore, “A Measure of Structural Change in Output,” *Review of Income and Wealth*, vol. 24, no. 1, pp. 105–118, 1978, doi: 10.1111/j.1475-4991.1978.tb00034.x.
- [9] L. Song, “The Influence of Industrial Structure Upgrading on Carbon Emission Efficiency in China,” *The Journal of Industrial Distribution & Business*, vol. 10, no. 2, pp. 7–15, 2019, doi: <https://doi.org/10.13106/ijidb.2019.vol10.no2.7>.
- [10] Y. Zhang and Y. J. Pu, “Industrial Structure Change and Its Impact on Energy Intensity,” *Journal of Industrial Economic Research*, vol. 2, pp. 15–67, 2015.
- [11] A. Dietrich, “Does growth cause structural change, or is it the other way around? A dynamic panel data analysis for seven OECD countries,” *Empir Econ*, vol. 43, no. 3, pp. 915–944, Dec. 2012, doi: 10.1007/s00181-011-0510-z.
- [12] D. J. Louhenapessy, “Analysis of Changes in the Sectoral Economic Structure Through Calculation of Ambon City Structural Change Index in 2015-2020,” *CITEK*, vol. 15, no. 1, pp. 50–60, 2021, doi: 10.51125/citaekonomika.v15i1.3490.
- [13] Eurostat, “Database - Eurostat,” 2022. <https://ec.europa.eu/eurostat/data/database> (accessed Jul. 18, 2022).
- [14] L. Cutz, O. Masera, D. Santana, and A. P. C. Faaij, “Switching to efficient technologies in traditional biomass intensive countries: The resultant change in emissions,” *Energy*, vol. 126, pp. 513–526, May 2017, doi: 10.1016/j.energy.2017.03.025.
- [15] MEKH, “Éves adatok. 7.4 Eurostat típusú országos részletes energiamérleg (éves) 2014-2020.,” *Magyar Energetikai és Közmű-szabályozási Hivatal*, 2022. <http://www.mekh.hu/eves-adatok> (accessed Sep. 26, 2022).