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Efficiency of Wood-Processing Enterprises—Evaluation Based on DEA and MPI: A Comparison between Slovakia and Bulgaria for the Period 2014–2018

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Abstract: The ongoing transition to a low-carbon, sustainable forest-based economy, and the adoption of circular bioeconomy principles in the wood-processing industry is associated with the optimization of natural resources, application of environmentally sustainable production technologies, adoption of technological and organizational innovations, and increased economic efficiency and competitiveness. The implementation of all these measures can help to reach the biggest challenge of our time in the fight against climate change in a cost-effective and competitive way. The aim of this study was to estimate the technical efficiency of wood-processing companies in the Slovak Republic and the Republic of Bulgaria by applying data envelopment analysis (DEA) and the Malmquist productivity index (MPI), and to reveal some factors for efficiency improvements. The economic efficiency evaluation based on official data was performed using selected indices of four wood-processing companies in each country in the period 2014–2018. The study implemented an output-oriented DEA model with constant returns to scale as a nonparametric linear approach for measuring the efficiency of production decision-making units (DMUs). The results obtained revealed that the studied Slovak companies were more efficient with better management in terms of machinery planning and overhead utilization. Markedly, the Bulgarian companies achieved better materials management and current planning quality. Increased economic efficiency of wood-processing enterprises in both countries can be realized through investments in innovative technological improvements, and enhanced research and development activities.

Keywords: wood-processing companies; data envelopment analysis; economic efficiency; circular economy; technical and organizational innovations; Malmquist productivity index

1. Introduction

In the recent years, the economic efficiency of industrial enterprises has been a leading topic of studies for researchers all over the world, who have been constantly looking for ways to improve it. Measuring the efficiency in production units and identifying the reasons of their inefficiency is a precondition to improve the performance of any production unit [1]. According to Martic et al. [2] efficiency means that desired goals are achieved with the minimum use of the available resources. Economic efficiency, or cost efficiency, represents the total efficiency of a production system [3]. Economic efficiency is consisted of two types of efficiency, i.e., allocative efficiency, related to producing maximum output subject to a given input, and technical efficiency, concerning the utilization of a specific combination of inputs to produce maximum output [4]. In terms of resource allocation, economic efficiency concerns maximizing the value of output from given resources and/or raw materials. The assessment of economic efficiency of any enterprise is based on a comparison of costs and effects of implemented economic activities [5].

The wood-based industries in the European Union (EU) countries cover a wide range of downstream activities, including wood-processing and furniture industries, pulp and paper manufacturing, and the printing industry. In 2018, about 397,000 companies were active in wood-based industries across the EU-27, representing 19.6% of the EU manufacturing enterprises with an estimated gross value added (GVA) of EUR 139 billion [6]. In forest-based industries like wood processing, the optimal combination of various inputs and outputs could be vital [7–12].

Lähtinen [13] employed resource-based view (RBV) to evaluate the competitiveness of wood-processing companies, and stated that developing and maintaining a wide selection of tangible and intangible resources is the key to increase competitiveness and economic performance. In forest-based industries many authors deal with the measurement of economic efficiency and factors that generate and foster it in industrial organizations. In some of them, parametric approaches are used [14,15]. Sedivka [16] estimated the technical efficiency of 203 Czech sawmills using the parametric approach of the Cobb-Douglass production function equation. Prasetiyo et al. [17] used Pareto analysis, an X-Y matrix, and process capability analysis. In addition, many researchers have successfully implemented nonparametric methods like data envelopment analysis (DEA) to investigate efficiency and productivity of similar economic units using particular inputs to produce outputs. These methods do not make hypotheses about the functional relationship between inputs and outputs. DEA is a linear-programming-based, nonparametric approach [18], widely used to analyse the efficiency of a set of organizational units. Using DEA, Yin [19–21] investigated the efficiency of pulp and paper companies in the Pacific region. Helvoigt and Adams [22] as well as Salehirad and Sowlati [23,24] successfully implemented DEA for efficiency assessment of sawmills. In fact, DEA is suitable for the whole supply chain in forest-derived products [25,26]. Alzamora and Apiolaza [27] estimated the efficiency of pine logs as raw materials, while Susaeta et al. [28] successfully calculated the efficiency of an entire pine forest. Korkmaz [29] and Sporcic et al. [30] used DEA to calculate the efficiency of forestry units at the level of forest enterprises. In addition, a recent comparative study on the economic efficiency of Bulgarian and Slovak forestry companies outlined the major factors affecting the differences in efficiency indices by using the DEA Malmquist productivity index (MPI) approach [7]. Kovalcik [31] calculated DEA scores to compare the Slovak forestry efficiency to other European countries. Sari et al. [32] and Ma [33] estimated the efficiency of furniture enterprises, mainly small and medium enterprises (SMEs). Trigkas et al. [34] estimated the efficiency of the wood and furniture sector innovation system. Wood processing is an economic sector, strongly dependent on the natural resources. In this respect, Vahid and Sowlati [35] implemented a DEA study and analysis on the efficiency throughout the entire wood supply chain. Fotiou [36] studied the effects of material handling systems and purchase markets on the efficiency of Greek sawmilling companies. Nyrud and Baarsden [37] investigated the efficiency of Norwegian sawmilling using DEA, as well as the productivity growth by applying the MPI, and concluded that about 30% of the companies were producing efficiently when assuming constant returns to scale. In another study, the authors [38] directly implemented different DEA models to British Columbia primary wood producers in order to evaluate their scale, technical and aggregate efficiencies. Labour utilization and log consumption were considered as inputs, and chip and timber production as outputs in their models.

Bulgaria and Slovakia have roughly the same size, forest area coverage and scale of wood-processing industry; their comparison is therefore quite suitable. Both countries have undergone a transformation process from a planned economy to several stages of privatization, and both still have room for the improvement. The role of the slightly earlier transfer of state-owned assets to private ownership in Slovakia may have played a role, but companies that were established in the 1990s on a green field were also taken into account, so this argument, although it exists, may not have affected the results across the board. Last but not least, the relatively diverse focus of wood-processing methods in selected companies and the degree of wood processing and the production of semiproducts or semi-nonwood production operations (e.g., surface finishing of particleboard) could also influence the official data collected. Given the size and the manufacturing value of the wood-processing enterprises in Slovakia and Bulgaria, they play a significant role in the economy of both countries. Wood-processing companies have many common characteristics in terms of economic and social development during the 20th and 21st centuries. Comparing the business models applied in wood-processing industries in these two countries will provide the basis to reveal common mistakes or hidden inefficiencies and differences. Thus, it is important to evaluate the performance of wood-processing companies in order to ensure a high efficiency and competitiveness in their production and constant improvements in their economic performance. To succeed in competing environments, it is necessary to ensure optimally utilization of wood resources in line with the cascading principle, the circular sustainable management approach and the green transition in accordance with the European Green Deal [39].

The main purpose of the current study was to estimate the technical efficiencies of wood-processing enterprises in both countries using the DEA approach and reveal some factors that determine efficiency like scale of production, technical changes and productivity.

2. Materials and Methods

2.1. Data Envelopment Analysis (DEA)

DEA production frontiers are constructed using linear programming techniques, which give a piece-wise linear frontier that "envelops" the observed input and output data [40]. DEA includes various models. The key principle of applying DEA to measure the efficiency of production DMUs lies in maximizing its efficiency rate. DEA provides a complete picture of the operation at individual DMU levels, involving multiple performance factors in the efficiency evaluation. DEA assigns efficiency scores to all DMUs by comparing the efficiency score of each unit with that of its peers, and identifies a frontier including the best performers. According to returns to scale, as stated by Li et al. [41] it is the appropriate model if the DMUs operate at an optimal scale. The Charnes, Cooper and Rhodes (CCR) model, developed by Charnes et al. [42], proposed that the efficiency of DMUs can be obtained from the maximum of the ratio of weighted outputs to weighted inputs. The Banker, Charnes and Cooper (BCC) model, developed by Banker et al. [43], is applicable in variable returns to scale to estimate the pure technical efficiency. According to [44–46], the main task before using DEA is to define the purpose of the estimation. Mathematical equations of the implemented DEA output-oriented models [47,48] are as follows:

CCR for the period t:

$$\begin{gathered} \max \theta_o^t \\ \sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{i0} \\ \sum_{j=1}^{n} \lambda_j y_{rj} \geq \theta y_{ro} \end{gathered} \tag{1}$$

where λ_j are individual scalars of each DMU$_j$ $j \in [1, n]$, x_{ij} are amounts of inputs of type i in DMU j, x_{i0} is the amount of i-th input of DMU$_0$ being under efficiency estimation. If the additional constraint $\sum_{j=1}^{n} \lambda_j = 1$ is added, the model becomes the BCC with variable returns to scale.

2.2. Malmquist Productivity Index (MPI)

The Malmquist productivity index is a DEA-based index which measures the productivity change over time [49]. Malmquist [50] made a comparison of factor productivity, i.e., input in one period could be decreased to the level that the same output can be produced in the next period with lower input—the Malmquist input index. Caves et al. [51] decomposed the Malmquist input index to elaborate the so-called Malmquist productivity index. Fare et al. [52] measured the productivity change of a particular DMU by DEA. This research applies the decomposed Malmquist productivity index similar to that implemented by Cao et al. [53]:

$$M_{t,t+1} = TEC_{t,t+1} \times FS_{t,t+1} \tag{2}$$

where $M_{t,t+1}$ is the Malmquist productivity index for changes from period t to the period $t + 1$. In the current research, the periods were every two consequent years with statistically different efficiency scores θ_z $z \in [t, t + 1]$. $TEC_{t,t+1}$ are the pure technical efficiency changes between t and $t + 1$. Frontier shifts (FS) are the technological changes between t and $t + 1$ year. Cao et al. [53] used the conditions for $M_{t,t+1}$ outcomes that $M > 1$ means improvement in productivity, $M = 1$ no changes and $M < 0$ indicates productivity loss.

$$TEC_{t,t+1} = \frac{\theta_0^{t+1}\left(x_o^{t+1}; y_o^{t+1}\right)}{\theta_0^{t}\left(x_o^{t}; y_o^{t}\right)} \tag{3}$$

$$FS_{t,t+1} = \left(\frac{\theta_0^{t}\left(x_o^{t}; y_o^{t}\right)\, \theta_0^{t}\left(x_o^{t+1}; y_o^{t+1}\right)}{\theta_0^{t+1}\left(x_o^{t}; y_o^{t}\right)\, \theta_0^{t+1}\left(x_o^{t+1}; y_o^{t+1}\right)}\right)^{1/2} \tag{4}$$

where $\theta_0^{t}\left(x_o^{t+1};\ y_o^{t+1}\right)$ are the efficiency frontier in the period t compared with $t + 1$. Scores are delivered by inputs/outputs from period t compared to the DMU_0's inputs/outputs of the period $t + 1$. $\theta_0^{t+1}\left(x_o^{t};\ y_o^{t}\right)$ are the efficiency frontier in the period $t + 1$ compared to t. Efficiency scores are delivered by inputs/outputs from the period $t + 1$ compared to the DMU_0's inputs/outputs of the period t. If $TEC > 1$, there are positive technical efficiency changes in the current study this means the one euro of inputs x_0 $[x_{1,0}, \ldots, x_{in}]$ the year $t + 1$ produce more output to year t. This is because the applied DEA model is output-oriented. In other cases, there is worsening of input utilization when $TEC < 1$ and there are no changes in $TEC = 1$. The interpretations of the FS results are the same. Companies have improved their technologies if $FS > 1$, otherwise they have not.

The current study has used a "rule of thumb" [42], which determined the max number of inputs involved, i.e., two max inputs.

The object of the present study were eight wood-processing enterprises from the economic sector C16 "Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials" [54], i.e., four companies per country. The enterprises are big producers of lumber and wood-based panels—particleboard, fibreboard, and plywood. The technical efficiency derived from their activities is quite representative for the sector specifics of transforming wood into different value-added products.

3. Results and Discussion

3.1. Data Envelopment Analysis CCR Scores

The results were grouped into several combined efficiencies. Labour, being a leading resource and a main subject of managerial decisions, was included in all combined efficiencies. The output in all the CCR estimations was the annual turnover. The results for the combined efficiencies are presented in Table 1.

Table 1. Combined efficiencies of each country for the period of research.

Inputs	2014	2015	2016	2017	2018	Average	σ
Labour and Materials costs						-	-
Bulgarian	0.95	0.98	0.94	0.96	0.95	0.96	0.01
Slovak	0.87	0.38	0.88	0.87	0.94	0.79	0.21
Labour and Depreciations						-	-
Bulgarian	0.54	0.84	0.81	0.91	0.81	0.78	0.13
Slovak	1.00	0.92	0.90	0.91	0.90	0.93	0.04
Labour and Other Costs						-	-
Bulgarian	0.54	0.56	0.53	0.55	0.52	0.54	0.01
Slovak	0.98	0.98	0.96	1.00	1.00	0.98	0.01

The ability of the enterprises to combine labour and materials in the current activity is presented by the first efficiency. The efficiency of the current planning is revealed. With regards to this, the Bulgarian enterprises demonstrated a better performance. The efficiency reached about 0.96 with very low variations. The Slovak companies reached lower scores—0.79 with high variations to 0.21. It is obvious that any significant improvement in this efficiency was not achieved by both countries, but Slovak enterprises improved their scores in the last year of the study. Changes throughout the years of the study period are not significant. Comprehensive information about the reasons for the determined scores in labour and materials costs efficiency is presented in Table 2.

Table 2. CCR scores for DEA with inputs labour costs and materials costs for each enterprise.

DMU Name, Country	2014	2015	2016	2017	2018	Average	σ
Kronospan Bulgaria EOOD, BG	1.00	1.00	1.00	1.00	1.00	1.00	0.00
WELDE Bulgaria AD, BG	0.85	0.92	0.83	0.84	0.87	0.86	0.03
Kastamonu Bulgaria AD, BG	0.94	0.99	0.93	1.00	0.95	0.96	0.03
Coop Obnova, BG	1.00	1.00	1.00	1.00	1.00	1.00	0.00
Rettenmeier Tatra Timber, LLC, SK	0.83	0.44	0.86	0.87	0.94	0.79	0.16
PRP, LLC, SK	0.87	0.41	0.82	0.80	0.93	0.76	0.17
Kronospan, LLC, SK	0.93	0.49	1.00	1.00	1.00	0.88	0.18
Slovincom, LLC, SK	0.86	0.17	0.85	0.81	0.89	0.72	0.25

The reasons why the average efficiency of Bulgarian enterprises is higher than the efficiency of the Slovak ones is revealed in Table 2. Two clearly distinguishable leaders in terms of efficiency appeared, i.e., Kronospan Bulgaria EOOD and Obnova Cooperative. The efficiency throughout the study period is demonstrated by them. Their current activities were planned very well. The combination of labour and materials was optimal and was not disturbed by high labour costs or inadequate management of material resources. The reason for the stepwise increment of the Slovak efficiency is that in 2018 three enterprises were close to efficient ones and one company (Kronospan, LLC), demonstrated efficiency. This is possible if companies implement approaches [55–57] for production of wood-based panels that improve the materials management and production efficiency. Additional analyses with Student's paired tests for differences revealed that 2018 was the most different year—$p = 0.03$.

The scores in Table 3 reveal that in the recent years, the efficiency of labour and machinery in combination has improved significantly. In 2017, almost all businesses were efficient. The increased costs for labour and depreciations resulted in an increase in efficiency scores, i.e., the output per input was significantly increased. Slovak companies reached greater scores and consequently better combined labour with machines in the production process. The Bulgarian companies, however, lost scores of their efficiency in 2018. The leader in combining labour and machinery was the Slovak company PRP, LLC. The worst results were determined for Coop Obnova in Bulgaria, followed by Slovincom, LLC in Slovakia. The biggest difference was established between 2014 and 2018—$p = 0.02$. This means that the changes in these inputs required longer periods, similar to the materials management and current planning.

Table 3. CCR scores for DEA with labour and depreciations inputs.

DMU Name, Country	2014	2015	2016	2017	2018	Average	σ
Kronospan Bulgaria EOOD, BG	1.00	1.00	1.00	1.00	0.97	0.99	0.01
WELDE Bulgaria AD, BG	0.30	1.00	1.00	1.00	1.00	0.86	0.26
Kastamonu Bulgaria AD, BG	0.70	0.80	0.75	1.00	0.74	0.80	0.10
Coop Obnova, BG	0.16	0.57	0.50	0.65	0.54	0.48	0.15
Rettenmeier Tatra Timber, LLC, SK	0.98	1.00	1.00	1.00	1.00	1.00	0.01
PRP, LLC, SK	1.00	1.00	1.00	1.00	1.00	1.00	0.00
Kronospan, LLC, SK	1.00	0.96	0.98	1.00	1.00	0.99	0.02
Slovincom, LLC, SK	1.00	0.72	0.63	0.65	0.62	0.72	0.13

The results in Table 4 show that the so-called other costs are managed efficiently in Slovakia and inefficiently in Bulgaria. These results reveal a problem with any costs that do not add value. Such a situation puts the Bulgarian wood-processing companies in a less favourable position than the Slovak ones. Lower efficiency of other costs means that activities resulting in overheads are deeply ingrained in the Bulgarian firms. Slovak enterprises can reduce their unit costs easier than the Bulgarian ones. The worst performer in Table 4 is Coop Obnova. Being the largest plywood producer in Bulgaria, it is vital for the company to improve this efficiency and balance the other costs with labour workload. A significant difference was only found between 2015 and 2016, which means that the management of the supplementary activities within companies remained stable during the examined period without any improvements.

Table 4. CCR scores for DEA with labour and other cost inputs.

DMU Name, Country	2014	2015	2016	2017	2018	Average	σ
Kronospan Bulgaria EOOD, BG	1.00	1.00	1.00	1.00	0.97	0.99	0.01
WELDE Bulgaria AD, BG	0.30	0.34	0.30	0.31	0.30	0.31	0.01
Kastamonu Bulgaria AD, BG	0.70	0.71	0.67	0.72	0.64	0.69	0.03
Coop Obnova, BG	0.16	0.18	0.16	0.18	0.18	0.17	0.01
Rettenmeier Tatra Timber, LLC, SK	1.00	1.00	1.00	0.99	1.00	1.00	0.00
PRP, LLC, SK	0.93	0.92	0.86	1.00	1.00	0.94	0.05
Kronospan, LLC, SK	1.00	1.00	1.00	1.00	1.00	1.00	0.00
Slovincom, LLC, SK	1.00	1.00	1.00	1.00	1.00	1.00	0.00

When the standard deviations are averaged by country, interesting results were obtained regarding the stability of the technical efficiency. Bulgarian companies were highly efficient in combining labour and materials at 1% deviation on average per enterprise, in contrast to the Slovak ones at 19%. The Slovak businesses were stable in the combination of labour and machinery, at 4%, while the Bulgarians had a deviation of 13%. These results show, even before the calculation of the Malmqvist index, that countries were stable in applying certain practices in the organization of wood-processing industries.

3.2. Malmquist Productivity Index Results

To implement the Malmquist productivity index (MPI) from Equations (2)–(4), it is necessary to determine statistically significant differences between every two years. The longer period between significantly different years means that the enterprises could have implemented some real changes in technology or scale of production. For the purpose, CCR scores should be tested for normality. The results for the Shapiro–Wilk test for normality are presented in Table 5.

Table 5. p-values for Shapiro-Wilk test for normality, H0–distribution is normal.

Inputs	Labour Costs/Materials Costs	Labour Costs/Depreciations	Labour Costs/Other Costs
2014	0.71	0.00	0.01
2015	0.14	0.00	0.01
2016	0.92	0.00	0.04
2017	1.00	0.97	0.00
2018	0.87	0.01	0.01

The results given in Table 5 show that only the scores of the model with labour costs and material costs as inputs were normally distributed. Consequently a paired t-test is suitable here. All other models were not normally distributed and the method for differences is the Wilcoxon matched-pairs rank sum test. The significance of year-to-year differences is presented in Table 6.

Table 6. Results of tests for differences.

t-Test p = 0.05, H0: No Differences				
	Labour costs/Materials costs		-	-
-	2015	2016	2017	2018
2014	0.06	0.92	0.78	0.03
2015	-	0.07	0.049	0.048
2016	-	-	0.74	0.04
2017	-	-	-	0.15
Wilcoxon matched-pairs rank sum test, p = 0.05, H0: No differences				
	Labour costs/Depreciations		-	-
-	2015	2016	2017	2018
2014	0.35	0.39	0.19	0.35
2015	-	0.22	0.37	0.19
2016	-	-	0.048	0.88
2017	-	-	-	0.048
	Labour costs/Other costs		-	-
-	2015	2016	2017	2018
2014	0.25	0.16	0.12	0.99
2015	-	0.048	0.87	0.62
2016	-	-	0.12	0.99
2017	-	-	-	0.25

The results in Table 6 show that the most significant changes occurred in the inputs of labour and materials, while the changes in machinery and labour appeared in the last two years. The MPI results for CCR comparison with labour and material costs as inputs for the period 2014–2018 are presented in Table 7.

Table 7. MPI results for CCR with labour and materials costs as inputs, t = 2014, $t + 1$ = 2018.

DMU Name, Country	θt	$\theta(t+1)$	$\theta t+1(xt; yt)$	$\theta t(x(t+1); y(t+1))$	*TEC*	*FS*	MPI
Kronospan Bulgaria EOOD, BG	1	1	1	0.996	1	0.998	0.998
WELDE Bulgaria AD, BG	0.85	0.87	0.903	0.814	1.024	0.938	0.96
Kastamonu Bulgaria AD, BG	0.94	0.95	1	1	1.011	0.995	1.005
Coop Obnova, BG	1	1	1	1	1	1	1
Rettenmeier Tatra Timber, LLC, SK	0.83	0.94	1	0.878	1.133	0.881	0.997
PRP, LLC, SK	0.87	0.93	1	0.866	1.069	0.9	0.962
Kronospan, LLC, SK	0.93	1	1	0.91	1.075	0.92	0.989
Slovincom, LLC, SK	0.86	0.89	0.917	0.831	1.035	0.936	0.968
Bulgarian, average					1.009	0.983	0.991
Slovak, average					1.078	0.909	0.979

The results given in Table 7 show that all enterprises have improved their net technical efficiency. Technical efficiency of a wood-processing business shows how well and efficient the company is able to use its resources, logs and labour to produce its products, timber and chips [35–38]. The resources were managed to produce more considering investments by companies in 2018 in comparison with 2014. The most efficiently improved enterprise was Rettenmeier Tatra Timber, LLC with *TEC* = 1.133, but, unfortunately, the technology moved down to 0.881. Kastamonu Bulgaria AD and Coop Obnova-Bulgaria were the two enterprises with MPI $\geq$ 1. Coop Obnova did not record any improvements over the period. Any change of the labour organization was made that caused changes in used materials. Kastamonu AD achieved a slight increase of the MPI which may be attributed to the production of more wood-based panels (particleboards) per one EUR of labour and materials. Technology there went downwards. Noticeably, the technology in this comparison (Table 5) means that the changes of the labour costs and materials costs led to improvements in generating more revenues. This can be due to the purchase of new machinery, marketing activities or optimization of on the operational level [37,58]. Slovak enterprises improved significantly their technical efficiency. This means that they improved their materials management and workforce organization [32,59]. Technologically, they are a little behind. The index shows that the combination of labour with materials did not work to improve the efficiency of the production process. Slovak companies unambiguously demonstrated better operational management than Bulgarian ones.

The presented analysis in Table 8 shows the extent to which the equipment, in combination with the labour, generates the required effect. This reveals the ability of management to provide equipment that does not burden the enterprise budget with acquisition and leasing costs that are not proportional to market needs [60,61]. The lower values of the indices reveal that technological development and efficiency have not been achieved [62,63]. Table 8 shows that Slovak companies have selected more appropriate equipment, which generates a higher result than Bulgarian ones. Two companies can be distinguished, namely Coop Obnova and Slovincom. A significant technological leap was made by these companies in terms of equipment that adds value. The others have not made any improvement. Noticeably, the effect of the technological improvement appeared in materials costs, and not in the consumption of fixed capital—depreciations. The reason could be sought in the high price of the equipment or in the available equipment that do not add value into production process and final products. The second statement is definitely true for the Bulgarian enterprises. Some technological changes were gained, but the pure technical efficiency decreased. Acquisition of machinery and equipment like vehicles, administration buildings etc., caused high depreciations without significant positive effect on turnover.

Table 8. MPI results for CCR with labour and depreciations as inputs, t = 2017, t + 1 = 2018.

DMU Name, Country	θt	$\theta(t+1)$	$\theta t+1(xt; yt)$	$\theta t(x(t+1); y(t+1))$	*TEC*	*FS*	MPI
Kronospan Bulgaria EOOD, BG	1.000	0.969	1.000	0.938	0.969	0.984	0.954
WELDE Bulgaria AD, BG	1.000	1.000	0.960	1.000	1.000	1.020	1.020
Kastamonu Bulgaria AD, BG	1.000	0.735	1.000	0.710	0.735	0.983	0.723
Coop Obnova, BG	0.649	0.539	0.573	0.880	0.831	1.359	1.130
Rettenmeier Tatra Timber, LLC, SK	1.000	1.000	1.000	0.989	1.000	0.995	0.995
PRP, LLC, SK	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Kronospan, LLC, SK	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Slovincom, LLC, SK	0.649	0.617	0.573	0.723	0.951	1.152	1.095
Bulgarian, average	-	-	-	-	0.884	1.087	0.957
Slovak, average	-	-	-	-	0.988	1.037	1.022

As indicated in Table 9, in labour and other costs, a statistically significant difference appeared between 2015 and 2016. This is the only difference in these CCR assessments. This difference was investigated in order to reveal any technological or efficiency improvements. The results outlined that there was technological improvement in the Slovak wood-processing companies. The value transferred from the supply chain to their budgets was reduced that year by technological means. The Bulgarian enterprises did not manage to reduce the other costs like external services, taxes, fees etc. Activities like certification of the production [64,65] could be a good opportunity to consist the other costs with strategically defined perspectives to add value and gain revenues. The long-term sustainability and increased economic efficiency of wood-processing enterprises in both countries can be achieved by improvements in wood-processing management and investments in research and development activities [66–71].

Table 9. MPI results for CCR with labour and other costs as inputs, t = 2015, t + 1 = 2016.

DMU Name, Country	θt	$\theta(t+1)$	$\theta t+1(xt;yt)$	$\theta t(x(t+1);y(t+1))$	*TEC*	*FS*	MPI
Kronospan Bulgaria EOOD, BG	1.000	1.000	1.000	0.815	1.000	0.903	0.903
WELDE Bulgaria AD, BG	0.339	0.302	0.321	0.242	0.891	0.921	0.820
Kastamonu Bulgaria AD, BG	0.714	0.669	0.682	0.575	0.937	0.949	0.888
Coop Obnova, BG	0.177	0.161	0.160	0.134	0.910	0.961	0.874
Rettenmeier Tatra Timber, LLC, SK	1.000	1.000	1.000	0.845	1.000	0.919	0.919
PRP, LLC, SK	0.915	0.858	0.571	1.000	0.938	1.366	1.282
Kronospan, LLC, SK	1.000	1.000	1.000	0.810	1.000	0.900	0.900
Slovincom, LLC, SK	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bulgarian, average	-	-	-	-	0.934	0.933	0.871
Slovak, average	-	-	-	-	0.985	1.046	1.025

According to a previous study [7] on a similar topic and in context of the wood supply chain, it can be stated that companies in both countries are making efforts to improve and optimize their internal organizational frameworks in order decrease the share of external services, in contrast with the forestry companies in Bulgaria and Slovakia.

Markedly, research and investments in advanced, sustainable manufacturing technologies would give the wood-processing sector the attractiveness it needs towards the new generations and increase its competitiveness on the global market. In any case, the results of the analyses are encouraging and may help to further advance of the assessed enterprises and the whole economy of both countries as a strong part of the EU economy.

4. Conclusions

In this research, the technical efficiency of wood-processing companies in Bulgaria and Slovakia was investigated from different aspects. DEA, as the base method of the non-parametric approach, was adopted to provide more holistic efficiency measures. Enterprise-level data were incorporated in the Charnes, Cooper, and Rhodes (CCR) models to determine the technical efficiencies of each enterprise. The study clearly outlined the leading sources of efficiency in the studied enterprises. The CCR model showed the optimality in the combination of labour and other resources in generating more revenue per unit of resource. Slovak companies demonstrated better efficiency in terms of equipment used and management of indirect costs. Technological improvements which were introduced increased their overall efficiency. The Bulgarian companies focused mainly on the management of material resources. All improvements resulted in a good combination of labour and material resources. The implemented technological improvements failed to generate better results, with the exception of two companies. In Bulgaria, the emphasis is on working capital and all efforts are aimed at reducing it, thus reducing the inventories. Slovak companies were more strategically oriented. Their efficiency was more technologically induced than organizationally generated with optimal organization and operational planning.

In this way, entrepreneurs can see the leading sources of efficiency and pay great attention to human resources in the direction of training and better recruitment. A comprehensive assessment of economic efficiency should take into account both factors dependent on the enterprise as well as the macroeconomic factors of the environment. It is therefore necessary for managers of wood-processing enterprises to have extensive and up-to-date knowledge of all relevant factors and conditions affecting the economic efficiency level.

The study limitations arose from the limited number of big wood-processing enterprises with similar production types in both studied countries. Another limitation comes from the requirements of the number of inputs and outputs compared to the number of enterprises—decision making units (DMUs) in the DEA model. The present study provides some answers and solutions for development of the large wood-processing companies in both countries. It needs to be further extended to smaller businesses. These limitations should be the subject of additional research.

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