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Research paper

Risk assessment of financing renewable energy projects: A case study of financing a small hydropower plant project in Serbia

Zeljko Spasenic *, Dragana Makajic-Nikolic, Sladjana Benkovic

University of Belgrade, Faculty of Organizational Sciences, Jove Ilica 154, 11000 Belgrade, Serbia

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A B S T R A C T

This study proposed a novel approach for conducting the credit risk assessment of financing a small hydropower plant (SHPP) project in Serbia via the failure mode and effects analysis (FMEA), which was modified by the Dempster–Shafer Theory (DST). A qualitative analysis of financing the SHPP project was performed to identify and describe the risk events that may cause loan default. To conduct the risk assessment, experts with experience in SHPP project financing in Serbia were required to evaluate the occurrence and severity of the identified risk events and their ability to detect them. Considering the epistemic uncertainty to which they were exposed, the experts assigned multiple ratings and their mass functions according to DST. Thereafter, the proposed FMEA-DST methodology was applied to identify the risk events that required the special attention of credit risk managers. Finally, adequate mitigation strategies that will reduce the credit risk of SHPP project finance in Serbia were proposed for the identified risk events. The research results demonstrated the effectiveness of the proposed approach as a comprehensive framework, which credit risk managers can employ to evaluate project finance requests.

1. Introduction

Climate change and environmental degradation account for existing global threats. An effective response to these challenges involves the strong deployment of renewable energy sources (RES). With >50% of their gross final energy consumption accruing from RES, Iceland (83,7%), Norway (77,4%), and Sweden (60,1%) account for the highest RES shares in Europe in 2020. Conversely, Belgium (13%), Luxembourg (11,7%), Malta (10,7%), and Ukraine (9,2%) account for the lowest RES shares. At the very end is Russia with an RES share of <5% (Eurostat, 2021).

Sachdev et al. (2015) posited that small hydropower plants (SHPPs) would be the most cost-effective, reliable, and environmentally sound means of power generation if there was a potential for hydropower generation. Europe exhibits an SHPP development tradition. As of 2019, the continent had developed ∼52% of its SHPP potential with western Europe accounting for the world's highest development rate (85%). Additionally, Europe comprises the largest number of countries with established feed-in tariffs for SHPPs. However, the main obstacles hindering the future development of SHPPs are rigid environmental regulations and the negative perception of hydropower systems by many environmental organizations (UNIDO, 2019).

The energy infrastructure in Serbia was inherited from the Socialist Federal Republic of Yugoslavia; it was characterized by outdated production plants with low-level energy efficiency. A similar situation has been observed in other post-Yugoslav countries. Despite the significant progress that has been recorded in the RES share in the overall energy production, there is still significant potential for its deployment (Đurašković et al., 2021). Among the post-Yugoslav countries, Montenegro (43,7%) accounted for the highest share of RES in its gross final energy consumption, while North Macedonia (19,22%) accounted for the least. Between 2005 and 2020, the most significant progress was recorded in Serbia (from 14,33% to 26,30%), while the least progress was recorded in North Macedonia (from 15,7% to 19,2%). The highest consumptions of RES-based electricity were recorded in Montenegro (61,5%) and Croatia (53,8%), followed by Bosnia and Herzegovina (37%), Slovenia (35,1%), Serbia (30,7%), and North Macedonia (23,5%) (Eurostat, 2021).

In 2020, total electricity production in Serbia was 35.540 GWh. The country's electricity is majorly generated by coal-fired thermal power (68,6%), followed by hydropower plants (26,5%), wind power plants (2,5%), and combined heat and power plants (0,5%); the remainder (1,9%) is produced by small power plants (AERS, 2020). Serbia's energy strategy is centered on RES, whereby SHPPs are recognized as facilities that can contribute to the better utilization of the country's total hydropotential.

* Corresponding author.
E-mail address: zeljko.spasenic@fon.bg.ac.rs (Z. Spasenic).

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The construction of SHPPs in Serbia dates to 1900 when the first hydropower plant comprising a three-phase alternating current was built four years after the construction of the world's first power plant of this type (Marković et al., 2012). A total of 856 locations were designated in 1987 for the construction of SHPPs in Central Serbia; 13 locations were further selected in Vojvodina in 1989. The locations were mostly mountainous areas (western and southeastern Serbia) because the northern region, which is flatter, exhibits a significantly lower potential. As of 2019, there were 131 active SHPPs in Serbia, accounting for a combined capacity of 87,6 MW, which corresponds to a utilization of only 19% of the total potential (UNIDO, 2019).

Serbia aims to promote and support SHPP-based electricity production. As renewable energy assets have proven their resilience amidst the COVID-19 pandemic, it is reasonable to expect that an investment in this sector will significantly interest investors (IRENA, 2020). However, the main barriers to the further development of SHPPs in Serbia are related to complicated legal procedures, non-versatile financing sources, and the limited awareness of the advantages and disadvantages of such projects among investors and creditors, as well as the public.

Project finance avails a suitable financial structure for developing SHPP; it allows investors with small balance sheets to implement projects. Thus, project finance is of significant advantage to corporate finance. According to this financing mechanism, a separate legal entity (a special purpose vehicle, SPV) must be established to solely own, manage, and operate an SHPP. This SPV will act as the borrower, and it is prohibited from engaging in any other business activity without the prior consent of its creditor. The market players who contribute to conditions that favor project finance are insurance companies that provide inexpensive coverages and banks that are willing to finance small-scale projects (Steffen, 2018).

The Serbian banking sector comprises 23 banks (NBS, 2022), although only some are active in the field of renewable energy project finance. Erste Bank, followed by UniCredit Bank, are the leading banks in SHPP project financing (Vejnović and Gallop, 2018). The other banks have accounted for insignificant or zero shares in this type of project. It is believed that more banks would finance these types of projects if there was an effective credit risk assessment framework that comprehensively analyzes the risks that are inherent to the development and exploitation of SHPP. According to Ciric (2019), if a creditor charges a reasonable interest rate (3%–4%), the construction of an SHPP could be a cost-effective project that repays in a shorter time than the incentive period guaranteed by the contract signed with the public enterprise, Electric Power Industry of Serbia (EPS), as the buyer of the produced electricity.

SHPP project finance is associated with many risks that may result in the debtors' inability to repay a project finance loan. Popović and Rajić (2019) reported examples of SHPP constructions that were based on misleading documentation (SHPP Zaskovci on the Živadinov Dol River in South-Eastern Serbia), SHPP construction without construction permits (SHPP Jovanovici on the Panjica River in western Serbia), SHPP construction without adequate planning (SHPP Jaruga on the Nera River in southern Serbia and SHPP Ravni on the Pristavica River in western Serbia), and SHPP construction without adequate environmental protection (SHPP construction in the Jošanica river basin, Kopaonik National Park). Although these risks are not finance-related, such projects are exposed to high credit risks and faced immediate bankruptcy if the regulatory authorities ban the SHPP operations. Vejnović and Gallop (2018) revealed that commercial banks financed SHPP projects had sparked protests among the local communities. Some of those protests interrupted the projects (SHPP on the Rakita River in southeastern Serbia). The impact of high environmental risks has been supported by recent studies. In research on six Serbian streams with operational SHPPs, Simonović et al. (2021) revealed their significant damaging impacts, such as increased water temperatures and dissolved oxygen, on the environment. The negative cumulative effects of SHPPs were observed in the Vlasina River, where nine SHPPs have already been constructed (Mitrović et al., 2021). The rivers in central Serbia, such as the Resava, Brusnička, and Golijska Moravica are also threatened by SHPP development (Mitrović and Simić, 2021). Seven municipalities in Serbia (Užice, Arilje, Pirot, Bor, Svrljig, Paraćin, and Ćićevac) have imposed restrictions on SHPP development to address its accompanying environmental concerns.

Compared with the environmental risks, the others are more evident and financial. For example, insufficient cash inflow may be caused by insufficient electricity production owing to inadequate hydrology or equipment. A project may be overwhelmed by the incurred debt if the creditors finance its cost overrun. As the databases of the frequency of these risks (financial) are unavailable and considering that banks hesitate to share information regarding less-successful placements, the occurrences of such risks in some projects can only be confirmed via interviews with experts. Shaktawat and Vadhera (2020) identified the exigency of comprehensive risk management in hydropower projects. However, they did not analyze it from the creditors' perspective, that is, they focused more on large-scale HPP than on SHPP projects.

Thus, this study proposes a novel approach for conducting a credit risk assessment that focuses on the creditors. This approach may benefit creditors because a newly established SPV is, in fact, a startup company with no business history or financial figures. Consequently, the standard rating models and risk assessment procedures that apply to corporate clients are ineffective for this type of credit request. Further, qualitative analysis and the hazard identification of the risk of financing an SHPP project were performed via the failure mode and effects analysis (FMEA). To eliminate the uncertainty of the FMEA ratings obtained from several experts, FMEA was modified by the Dempster–Shafer theory (DST), FMEA-DST. Huang et al. (2020) confirmed that the application of the DST-improved FMEA method (FMEA-DST) bridges a research gap and represents an opportunity to discover new application fields. Additionally, Wang et al. (2019a) proposed the application of the developed FMEA-DST risk assessment approach as an interesting research direction for solving risk analysis issues in other practical and non-technical areas.

Following the identified research gaps, this study focuses on applying the improved FMEA-DST in a new area. Therefore, this study contributes to the existing literature in at least threefold: (*i*) it offers a detailed overview of the risk events that are associated with SHPP projects and may cause debt default, as well as are relevant to creditors during the credit approval process; (*ii*) this study represents the first outline of an in-depth evaluation of the application of FMEA-DST in finance for credit risk assessment; and (*iii*) it avails an applicable and comprehensive tool for improving the credit approval and decision-making process to relevant policymakers.

The remainder of this paper is organized, as follows: Section 2 presents the literature review; Section 3 presents the background of the proposed methodology; Section 4 explains the FMEA-DST methodology in detail; Section 5 discusses the risks associated with SHPP project finance, as well as the survey design, application of the proposed method, research results, and sensitivity analysis; and Sections 6 and 7 present the research implications and conclusions, respectively.

2. Literature review

FMEA was originally employed as a method for evaluating faults in quality management, although its versatile applications have been confirmed by different research and practice fields that are mostly focused on some specific industries, such as the manufacturing, marine, aerospace, healthcare, and electronics industries (Huang et al., 2020). Several publications on the application of FMEA in finance are available in the extant literature. Some pioneering previous papers theoretically demonstrated how FMEA, as a part of the Six Sigma projects, can be applied to finance (Krehbiel et al., 2009) and logistics factoring financing risk analysis. Subsequently, the practical applications of FMEA were developed and reported. For example, FMEA was applied to the evaluation of the risks of project finance in EPS (Nikolić et al., 2011), identification of the risk of losing emergency department revenue (Shahrami et al., 2013), and auditing of corporate financial risks (Yanjun, 2014). In recent years, FMEA has exhibited new applications in finance with the following goals: to assess financial, as well as production and marketing risks, in the livestock subsector of Indonesian agriculture (Wantasen et al., 2020); to conduct a compliance risk assessment in the Central and Eastern European commercial banks (Bognár and Benedek, 2021); to conduct financial and other risk assessments in public–private partnerships (PPP) (Akçay, 2021); to assess the risk that is associated with utilizing the financing application, Financore, which displays consumer credit-related data and information (Triana and Pangabean, 2021).

The application of improved FMEA procedures is necessary because traditional FMEA has been extensively criticized in the literature owing to several drawbacks, the most significant of which include the following: (*i*) it barely offers a precise evaluation of the risk factors that are required to calculate risk priority numbers (RPNs), (*ii*) the risk factors are equally weighted in RPN calculations employing FMEA, and (*iii*) the RPNs cannot be employed to objectively measure the efficiency of the proposed corrective actions. Liu et al. (2013) reported a detailed overview of the major shortcomings of FMEA. The outlined shortcomings are principally caused by epistemic uncertainty, which is due to a lack of relevant knowledge, as well as incomplete or subjective data (e.g., expert opinion). Contrarily, aleatoric uncertainty is due to inherently random effects. Consequently, epistemic and aleatoric uncertainties are the reducible and irreducible parts of the total uncertainty, respectively (Asadujjaman and Zaman, 2018; Hüllermeier and Waegeman, 2021).

FMEA has been combined with various methods to incorporate it with uncertainties. For example, Pillay and Wang (2003) employed the fuzzy rule base and grey relational theory to incorporate linguistic terms and approximate reasoning into FMEA. Jee et al. (2015) employed a set of fuzzy rules whose size had been reduced by applying genetic algorithms to treat the inaccuracy and uncertainty of the utilized experts' ratings of FMEA risk factors. Chai et al. (2016) employed perceptual computing to analyze the linguistic uncertainties in FMEA ratings that were obtained by a group of decision-makers. However, DST is employed in this study.

DST, which is also called the evidence theory, was introduced by Arthur Dempster (1967) and extended/formalized by Glenn Shafer (1976) as an extension of the Bayesian probability theory to reduce the epistemic uncertainties of available data. FMEA and DST (FMEA-DST) have been jointly utilized since the 1980s primarily for conducting the risk analyses of technical systems. One of their first applications was in the aviation industry where Garcia-Ortiz and Cundiff (1988) employed FMEA and built-in test (BIT) data as evidence in DST-based equipment diagnostics. Several subsequent applications in the aviation industry employed DST to eliminate the uncertainty of the FMEA ratings obtained from several experts (Yang et al., 2011; Su et al., 2012; Chen and Deng, 2018). A similar approach was employed in the marine industry to assess possible failure modes in fishing vessels (Chin et al., 2009; Certa et al., 2017; Seiti et al., 2018), marine diesel engines (Emovon, 2016), and on-board ships (Suo et al., 2020). Kulkarni and Johnson (2012) considered the theoretical aspect of the application of FMEA-DST in which multiple failures can occur simultaneously and where experts rank all possible failure combinations. However, the application of such an approach to many failures can cause a combinatorial explosion. To reduce the uncertainties of expert FMEA ratings, DST has also been employed in the energy industry to assess the failures of microelectromechanical systems (Jiang et al., 2017) and power transmission equipment (Wang et al., 2018), as well as in the mining industry to conduct risk analyses in steel production (Li and Chen, 2019; Wang et al., 2019b). The uncertainties of FMEA ratings were addressed via DST in the risk analyses of aerospace electronics (Guo, 2016) and electronics (Liu and Xiao, 2019) manufacturing projects. Regarding project risk assessment, DST has been solely applied to the risk analysis of construction (Taroun and Yang, 2013) and investment (Shved, 2017) projects, as well as the assessment of environmental risks (Hatefi and Tamošaitienė, 2019).

In finance, DST has been solely applied continuously to stock portfolio selection (Sevastianov and Dymova, 2009; Thakur et al., 2016, 2018; Salehy and Ökten, 2021). DST can be applied to several areas, such as financial distress prediction models (Beynon, 2005; Xiao et al., 2012) and for developing the financial early warning models (Zhang et al., 2013). DST was also employed to assess fraud risks in the audit of a financial statement (Gao et al., 2011) and determine the financial audit strategy (Vîlsănoiu, 2012).

In banking, DST was applied for credit risk assessment (Zhu and Wang, 2008; Lin and Huang, 2009) to detect cyber threats to financial institutions, particularly account takeovers (Coppolino et al., 2015), as well as to detect suspicious banking transactions (Khanuja and Adane, 2018). DST was recently employed to deal with the uncertainties in the assessment of the financial risk factors of projects (Albogami et al., 2021, 2022). The extant literature did not report any example of the joint application of FMEA and DST in project financing or credit risk assessment.

3. Background

3.1. FMEA

FMEA is designed to (*i*) identify and elucidate potential failure modes, as well as their causes and effects on specific systems or consumers; (*ii*) assess the risks that are associated with the identified failure modes and prioritize issues for corrective actions; and (*iii*) identify and implement corrective actions to mitigate the most significant concerns (Carlson, 2012). Therefore, the FMEA design is consistent with the credit risk management process and its expected outcomes.

According to Ericson (2005), the FMEA procedure includes the following steps in a broader sense: the formation of an FMEA team; the establishment of rules and roles; the gathering and studying of relevant information; the identification of the components, processes, and events to be analyzed; the identification of methods, effects, causes, and actions of each component, process, and event; the risk assessment; the prioritization of the corrective actions; the performance of such corrective actions and reassessment of the risks; and the forwarding and reporting, as well as periodic repetition of the established procedure, if necessary.

Risk assessment accounts for the key step of FMEA because the adequacies of the corrective and preventive actions depend on

Table 1
Occurrence rating criteria.

Occurrence	Rating	Possible risk event probability
Extremely low	1	<0,1%
Remote	2	0,1–0,25%
Low	3	0,25–0,8%
Relatively low	4	0,8–1,5%
Moderate	5	1,5–2,5%
Moderately high	6	2,5%–5%
High	7	5–12,5%
Repeated failures	8	12,5%–33%
Very high	9	33%–50%
Extremely high	10	≥50%

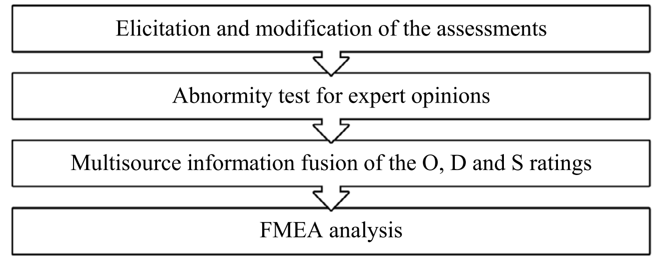

Fig. 1. Steps of FMEA-DST methodology.
Source: Adopted from Suo et al. (2020).

the results of risk assessment, which is expressed as an RPN. RPN is a quantitative FMEA result, which is employed to rank (prioritize) the identified failure modes. It is mathematically calculated by multiplying the numerical values for three risk factors, namely occurrence (O), detection (D), and severity (S), as follows:

$$RPN = O \cdot D \cdot S, \tag{1}$$

where O, D, and S are rated on scales of 1–10.

Carlson (2012), Ericson (2005), and Ayyub (2003) explained the main components of RPN, as follows are explained by:

- **Occurrence rating** refers to the likelihood that the failure mode and its associated cause will be present in the item being analyzed. This rating is relative rather than absolute and is determined regardless of the severity or detection rating.
- **Detection rating** measures the ability of the present controls to detect the causes before generating a failure mode and/or failure modes before causing effects.
- **Severity rating** refers to the significance of the effect on the consumers' requirements. It is driven by the failure effects and criticality and applies only to the effect. This rating must be the same each time an identical failure effect occurs.

Corrective actions must first focus on the highest-ranking concerns and critical items where the causes are not well elucidated. A rule of thumb is to pay close attention to RPNs above 125 (Ayyub, 2003), which is the normal average RPN ($5 \cdot 5 \cdot 5$); thus, failure modes above this average are considered more critical than those below it (Woo, 2017). RPNs must be recalculated after applying adequate corrective actions to test their efficiency for each failure mode. Other solutions must be proffered to mitigate the risk if it does not decrease sufficiently. The modified occurrence, detection, and severity rating scales are presented in Tables 1, 2, and 3, respectively. There are adjustments to the definitions of the category criteria, and these scales are utilized by experts for the risk assessment of events that relate to SHPP project finance.

Based on the calculated RPNs, a critical item list (CIL) can be prepared to avail an overview of the risk events that are considered critical to system reliability. CIL is a living document that contains all the possible causes of failure; it is employed to determine and generate the types of controls and procedures that are required to mitigate the risk events (Ostrom and Wilhelmsen, 2012).

3.2. DST

Although DST relies on the probability theory, it utilizes the concept of proposition rather than that of events; dissimilar to the probability theory, DST does not include additivity (Salicone and Prioli, 2018).

Let $\Theta = \{\Theta_1, \Theta_2, \ldots, \Theta_P\}$ be a limited set of mutually exclusive possible answers to a given assumption. The set, Θ, is called the frame of discernment, and $2^\Theta = \{\varnothing, [\Theta_1], [\Theta_2], \ldots, [\Theta_1 \cup \Theta_2], [\Theta_1 \cup \Theta_3], \ldots, \Theta\}$ represents its power set. Moreover, each $A \in 2^\Theta$ represents a proposition (Chen and Deng, 2018).

A mapping, $m: 2^\Theta \rightarrow [0, 1]$, such that $m(\varnothing) = 0$ and $\sum_{A \in 2^\Theta} m(A) = 1$, is called a mass function. Based on this mass function, the belief function, $Bel: 2^\Theta \rightarrow [0, 1]$, and plausibility function, $Pl: 2^\Theta \rightarrow [0, 1]$, of Proposition A can be defined, as follows (Salicone and Prioli, 2018):

$$Bel(A) = \sum_{B \subseteq A} m(B) \tag{2}$$

$$Pl(A) = \sum_{B \cap A \neq B} m(B) \tag{3}$$

It is evident that $Pl(A) = 1 - Bel(\bar{A})$ (where $\bar{A} = \Theta \backslash A$) and that $Pl(A) \geq Bel(A)$.

Function $Bel(A)$ represents the belief that Proposition A is correct, whereas $Bel(\bar{A})$ expresses the degree of doubt in Proposition A. The value of $Pl(A)$ indicates the extent to which the person does not doubt Proposition A, that is, the credibility of Proposition A. In DST, the belief and plausibility represent the lower and upper limits of uncertainty, respectively.

If $m(A) > 0$, A is called the focal element and the set of all focal elements represents the body of evidence. If several independent bodies of evidence exist, they must be combined such that each proposition will obtain a single mass function. This combined evidence was determined, according to the so-called combination rules. One of which is Dempster's rule of combination:

$$m(A) = \begin{cases} \frac{1}{1-K_i} \sum_{\cap A_i = A} \prod_{l \in L} m_i(A_i) & A \neq \varnothing \\ 0 & A = \varnothing \end{cases}, \tag{4}$$

where L is the set of sources and $K_i = \sum_{\cap A_i = \varnothing} \prod_{l \in L} m_i(A_i)$ is the normalization factor, which expresses the conflict among the sources of evidence.

4. Methodology

In the proposed FMEA-DST methodology, experts represent sources of evidence, while the discernment frames for each undesired event and each risk factor include an FMEA ratings of 1–10. The schematic of the methodology is illustrated in Fig. 1.

4.1. Elicitation and modification of the assessments

Let N represent a set of identified undesired events. This step aims to collect and standardize the expert answers regarding the elements of N. Further, let L represent a set of the experts involved in availing the O, D, and S ratings of the undesired events

Table 2
Detection rating criteria.

Detection	Rating	Description
Certain	1	Risk will be detected during the credit approval process (risk is obvious).
Almost certain	2	Risk will be most likely detected during the credit approval process.
High	3	Risk may be detected if a more detailed analysis is performed during the credit approval process.
Moderately high	4	Risk may be detected if a more detailed analysis is performed during the credit approval process and more detailed information is collected.
Moderate	5	Risk may be detected if a more detailed analysis is performed during the credit approval process, more detailed information is collected, and additional resources are engaged.
Low	6	Risk may be detected if additional resources are engaged. Those resources would not be engaged under ordinary circumstances.
Very low	7	It is very hard to detect risk during the credit approval process.
Remote	8	It is extremely hard to detect risk during the credit approval process.
Very remote	9	Risk cannot be detected during the credit approval process except in very rare cases.
Impossible	10	Risk cannot be detected during the credit approval process.

Table 3
Severity rating criteria.

Severity	Rating	Description
None	1	No effect on the quality of placement; debtor regularly repays the loan throughout the credit repayment period
Very minor	2	May cause a materially insignificant loss for the bank; very rare overdue credit repayment
Minor	3	May cause a materially insignificant loss for the bank; occasional overdue credit repayment
Low	4	May cause a materially significant loss for the bank; placement demands higher level of attention from the department for credit risk management; regular overdue credit repayment up to 30 days
Moderate	5	Significant increase in the probability of a materially significant loss for the bank; exposure should be secured with additional collateral; regularly overdue on credit repayments in excess of 30 days
Moderately high	6	High probability of a materially significant loss for the bank; placement will be relocated to department for restructuring (problematic placement management); frequently overdue on credit repayments in excess of 30 days
High	7	Credit repayment may continue with restructuring; bank will surely experience a materially significant loss; loan requires additional collateral or owner deposit which would reduce the outstanding placement amount
Very high	8	Credit repayment may continue only with additional investment by owner which reduces credit indebtedness and monthly credit installment
Extremely high	9	Leads to a halt in credit repayment in a very short period of time; loss for the bank in the amount of placement minus the market value of collateral
Hazardous	10	Leads to a simultaneous halt in credit repayment by the debtor; loss for the bank in the amount of placement minus the market value of collateral

in N. For each risk factor, $i \in \{O, D, S\}$, the discernment frame is $\Theta_i = \{1, 2, 3, 4, 5, 6, 7, 8, 9, 10\}$. The results of the assessments are represented by $m_{il}^{j}(k)$, where $l \in L$, $j \in N$, $i \in \{O, D, S\}$, and $k \in \Theta_i$.

In most FMEA-DST applications, the discernment frame consists only of Set Θ, whereas the other elements of its power set are excluded from the analysis for the following two reasons: first, this approach is consistent with the FMEA method, which assesses the risks of individual events rather than combinations of events. Second, the FMEA-DST evaluation of the power set of Θ results in a combinatorial explosion for many undesired events considering that its cardinality is 2^{Θ} (Kulkarni and Johnson, 2012).

4.1.1. Modification of the unique assessment

If an expert gives a unique rating r for a risk factor, then $m_{il}^{j}(r) = 1$ and $m_{il}^{j}(k) = 0$ for all $k \neq r$. This rating can be modified and transformed into three adjacent rating values using a Gaussian distribution. According to Su et al. (2012), the assigned r is the mean, and standard deviation = 0.5; thus, $m_{il}^{j}(r)$ is given, as follows:

$$f(r,k,0.5^2) = \frac{1}{0.5\sqrt{2\pi}} e^{-\frac{(k-r)^2}{2\cdot 0.5^2}} \tag{5}$$

By applying Eq. (5), $m_{il}^{j}(r)$ would be equal to 0.8, and the mass functions of its adjacent rating values, $m_{il}^{j}(r-1)$ and $m_{il}^{j}(r+1)$, would be equal to 0.1 (Su et al., 2012).

4.1.2. Simplification of the discernment frame

As the expert ratings can be between 1 and 10 for each risk factor, the data for further analysis include the discernment frames, expressed as $\Theta_i = \{1, 2, 3, 4, 5, 6, 7, 8, 9, 10\}$, of each of n undesired event. However, for practical purposes, these discernment frames can be simplified according to the experts' ratings. If $\min X|_{X\subseteq\Theta_i}$ and $\max X|_{X\subseteq\Theta_i}$ are the minimal and maximal ratings of the ith risk factor of the jth undesired event attributed by the lth expert, respectively; thus, for each risk factor of each undesired event given by each expert, the discernment frame can be reduced to the following (Yang et al., 2011):

$$\begin{aligned} &\Theta_{il}^{j} = \left\{\min X|_{X\subseteq\Theta_i^j}, \min X|_{X\subseteq\Theta_i^j} + 1, \ldots, \max X|_{X\subseteq\Theta_i^j}\right\} \\ &j \in O, D, S, \\ &j \in N, \\ &i \in L \end{aligned} \tag{6}$$

4.2. Abnormity test for expert opinions

Given that the discernment frames, Θ_{il}^{j}, consist only of the elements of Θ, the numerator in Eq. (4), which is the sum of products, would be reduced to the product of $m_{il}^{j}(k)$ (Eq. (7)). The risk factors that are attributed by some experts to a certain undesired event might differ significantly from the ratings by other experts, resulting in a situation whereby an undesired event, $j \in N$, and a risk factor, $i \in \{O, S, D\}$, would exhibit a discernment frame, Θ_{iq}^{j}, such that $\Theta_{il}^{j} \cap \Theta_{iq}^{j} = \varnothing$ for each $l \in L\backslash q$. In such a situation, $m_{il}^{j}(k)$ in Eq. (4) will be equal to zero for all the values of k, and Dempster's combinatorial rule cannot be applied.

Some authors mitigated this by modifying Dempster's combination rule (Yang et al., 2011; Su et al., 2012) by introducing a discounting coefficient into it (Li and Chen, 2019; Chen and Deng, 2018) or proposing a new aggregation method (Wang et al., 2018). To determine the experts' scores that must be excluded from the analysis, Huang et al. (2018) utilized the belief entropy, while Suo et al. (2020) employed a normal distribution to define the domain of acceptable expert opinions. However, most authors did not have issues with conflicting data and ignore this shortcoming (Kulkarni and Johnson, 2012; Emovon, 2016; Certa et al., 2017; Seiti et al., 2018; Wang et al., 2019a).

In this study, the following simple rule was proposed: if some undesired events, $j \in$ N, and risk factors, $i \in \{O, S, D\}$, exist in the discernment frame, Θ_{iq}^{j}, such that $\Theta_{il}^{j} \cap \Theta_{iq}^{j} = \varnothing$ for each $l \in L\backslash q$, such a discernment frame, Θ_{iq}^{j}, must be excluded from the risk assessment. Therefore, the union of the remaining discernment frames, Θ_{il}^{j}, becomes the discernment frame, Θ_{i}^{j}, for the ith risk factor and jth undesired event. The proposed approach eliminates conflicting experts' opinions, given that the conflict coefficient, K_i, in Eq. (4) can be calculated via the proposed combination rule. The rationale behind this rule is to exclude the opinions of experts that are risk-averse against specific risk events owing to a previous negative experience that might be exceptional. A similar rationale applies if an expert ignores a specific risk event because of a lack of previous negative experience (see Section 4.2).

4.3. Multisource information fusion of the O, D, and S ratings

In FMEA ratings, propositions cannot take the value from the entire power set, 2^{Θ}, but only from the sets, Θ_{il}^{j}. Therefore, the final values of the mass function for the risk factor, $i \in \{O, D, S\}$, of the undesired event, $j \in N$, can be obtained via the modified combination rule, as follows (Yager, 1987; Giuseppe et al., 2016):

$$m_i^j(k) = \begin{cases} \frac{1}{1-K_i} \prod_{l\in L} m_{il}^{j}(k) & k \in \bigcap_{l\in L} \Theta_{il}^{j} \\ 0 & \text{otherwise} \end{cases}, \tag{7}$$

where $K_i = \sum_{(\exists v,u\in l) k_v \neq k_u} \prod_{l\in L} m_{il}^{j}(k_l)$.

4.4. FMEA analysis

Given that all the mass functions, $m_i^j(k)$, are determined, the final risk ratings for each risk factor, $i \in \{O, D, S\}$, for each undesired event, $j \in N$, will be obtained, as follows (Suo et al., 2020):

$$RPN_i^j = \sum_{k\in\Theta_i^j} k \cdot m_i^j(k),\ i \in \{O, D, S\}, j \in N, \tag{8}$$

and RPN for an undesired event, $j \in N$, can be calculated thus:

$$RPN^j = RPN_O^j \cdot RPN_D^j \cdot RPN_S^j. \tag{9}$$

For each risk event, the obtained RPN values will include the estimates of all the experts regarding the O, D and S in a manner that reduces the uncertainty of their responses. Thereafter, the events will be ranked according to their RPN values (from highest to lowest). This ranking also refers to the priority of the risk mitigation measures on the project. Put differently, measures must first be taken to reduce the risk of the highest-ranking events and so on for as long as there are resources available to treat the risk.

5. Application of the proposed methodology

This section discusses the application of the proposed FMEA-DST methodology, as follows: Section 5.1 describes the final list of the 17 risk events that were analyzed by three experts. The relatively small number of experts (3–5) corresponds with previously employed approaches (Certa et al., 2017; Chen and Deng, 2018; Hu et al., 2020; Jiang et al., 2016; Su et al., 2012; Suo et al., 2020; Wang et al., 2018, 2019b; Yang et al., 2011). Additionally, three experts are generally involved in the credit risk process in which the same credit request would be analyzed by the risk analyst, the head of the credit risk department, and the chief risk officer. The involvement of more experts does not exert any influence on the application of the methodology except if it requires additional computation. The initial survey results of the experts' assessments are $m_{il}^{j}(k)$ where $i \in \{O, S, D\}$, $l = \overline{1,3}$, $j = \overline{1,17}$, and $k \in \Theta_i = \{1, 2, 3, 4, 5, 6, 7, 8, 9, 10\}$. The quantitative results of the application of the methodology are reported in Section 5.2. Table 6 presents the survey results, following the modification of the unique assessments and application of the abnormity test, while Table 7 presents the final values of the conflict coefficients among the assessments, risk factors, and RPNs. To confirm the robustness of the proposed model, a sensitivity analysis was conducted, as described in Section 5.3, by assigning weights to the experts based on five different scenarios.

5.1. Hazard identification

The failure of project finance transactions generally constitutes an event of debt default. In this study, debt default is defined as a debtor's inability to repay a loan as per the initially agreed financing term. Alternatively, the realized credit risk of a borrower is considered a failure of project finance.

Shaktawat and Vadhera (2020) presented a detailed list of the risks that are associated with hydropower projects; this list was utilized as the starting point of risk analysis. Further, the interviews of the experts facilitated the identification and description of the final list of 17 different events that might cause the failure of project finance.

Risk events are divided into the following three subgroups, which are identified by the point in the life cycle of a project where such risks occur: (*i*) the project realization phase (the loan drawdown phase, events 1-8), (*ii*) the project exploitation phase (the credit repayment phase, events 9–15), and (*iii*) combination of both phases (events 16 and 17). Each risk event is described, as follows:

1. *Failure to know your customer's (KYC) bank policy.* Reputational risk is a "risk that accrues from negative perception on the part of the stakeholders, which can adversely affect the ability of a bank to maintain existing business relationships or establish new ones, as well as sustain continued access to funding sources" (BIS, 2018). The inadequacy of KYC standards can expose banks to reputational and other risks (BIS, 2001). This study considers a reputational risk as one, which exists when a bank finances the businesses of clients that are involved in fraudulent activities when a bank finances an SHPP project that is in severe conflict with legislation or does not comply with environmental standards and requirements.
2. *Sponsor abandons the realization of a project.* The decision to abandon a project is at the sole discretion of the sponsor and can be driven by multiple factors, which might be personal, family-related, or commercial. The probability of this risk event is not high, and the possibility of identifying it is low if there is an intersection of the private and commercial factors, except for the sponsor's business history that indicates such behavior.
3. *Incomplete project documentation.* The uninterrupted realization of a project requires complete project documentation that fully complies with the existing legislation. This risk infers that it is impossible to acquire missing documentation during the construction or exploitation of an SHPP. Although the documentation process is complex, experienced creditors have appropriate procedures and rely on predefined documentation checklists.
4. *Inexperienced designer.* Unintentional omissions(s) in a project may be caused by the project designer's inexperience. Banks generally tend to cooperate with designers with proven track records in completing similar projects; however, the choice of the designer is at the discretion of the investor. Designers' expertise can be supported by a reference list, although the possibility of omissions would still exist. Elucidating the costs and time for completing a project based on the designer's inexperience can cause cost overruns. Cost overrun is the positive difference between the actual project cost and the projected budget. Further, there are other risks (5, 6, and 7) that can produce budget overruns, as evaluated below.
5. *Intentional underestimation of the project budget.* The project budget depends on several factors, such as the characteristics of the microlocation, the type and capacity of the SHPP, the length of the pipeline, the composition of the soil, and the type of equipment installed. The project budget can be intentionally understated to reduce the investors' share of capital financing because the investor is required to contribute a certain amount of equity to the project. Here, the investor expects the creditor to increase the loan financing after placing the initial tranches for the SHPP to be built for the project to enter the exploitation phase. Information asymmetry, as well as the irreversible nature of project financing, places the creditor in a subordinate position to the debtor.
6. *Cost overrun during groundwork* (during the excavation of land for the construction of a water intake, a machine house, or the installation of pipelines). This exhibits a moderate occurrence probability. The possibility of detection is low, and the severity is high. As the groundworks can be slightly larger than the construction works, this risk requires a greater degree of attention and is potentially more dangerous than the cost overrun during the construction works.
7. *Cost overruns during the construction work* (construction of the water intake and machine house). Given that the estimated size of the project is limited and the scope of the construction work is relatively small, it could be assumed in advance that the stated risk is limited in terms of the occurrence and severity of this specific risk.
8. *Public protests against SHPPs.* Numerous studies have revealed the negative influences of SHPPs on biodiversity and the environment (Tanović et al., 2020; Sousa et al., 2020; Özge Can Dogmus and Nielsen, 2020). Negative public sentiments have been witnessed toward SHPPs in Serbia amid the increasing numbers of civic protests, as well as municipalities that have banned the construction of SHPP in their territory. Public protests occur during the construction, as well as exploitation phases of SHPPs. The possibility of predicting public opposition is low; it is based on trends in public attitudes toward preserving the local communities (Mayeda and Boyd, 2020; Venus et al., 2020).
9. *Inadequate hydrological assessment.* The annual river flow and droughts account for the most significant hydrological variables of producing electricity from hydropower plants (EEA, 2019). This indicates that investors and creditors must comply with the operating conditions and the possible discrepancy between the projected and actual river flows. The potential river flow cannot be reliably predicted from a few years. This is one of the reasons why energy managers rely on a historical period of ∼10 years, although this is still a rather loose prediction owing to the stochasticity of the hydrometeorological process (Contreras et al., 2020). Thus, credit risk managers will rely entirely on the predictions of external river flows.
10. *Large seasonal oscillations in hydrology.* An SHPP cannot ensure constant electricity production during its useful life and a single calendar year because it depends highly on the variability in precipitation, snow cover, and seasonal weather conditions. The most critical period comprises the summer months during which droughts are expected. Creditors must diligently deal with seasonal variations in electricity production because they directly correlate with the cash inflow necessary for loan repayment.
11. *Inadequate equipment choice.* The selection of a turbine is based on the head (the vertical distance that the waterfalls) and flow or volume of the water at the construction site, the depth at which the turbine must be set, its efficiency,

and its cost (Okot, 2013). The optimal choice of equipment positively impacts project performance. Bank employees are not turbine experts; thus, they generally rely on external technical reports. Considering the uncertainties that are related to hydrology, the risk and detection are moderate, while the severity is high because an inadequate equipment choice cannot be corrected without additional investments and the redesign of the whole project, which will trigger a cost overrun.

12. *Risk of uncollectible receivables from EPS.* This represents the risk of a sole customer. The assessment of this risk involves calculating the probability of the bankruptcy of EPS. Banks can accomplish this by analyzing and determining the credit rating of EPS via a rating model for corporate clients. The particularity of this risk is that it is completely identical in all aspects across different SHPP projects.
13. *Inadequate connection of the constructed SHPP to the power distribution system.* This is solely the fault of the distribution system operator. It prevents the commercial exploitation of the full-capacity SHPP. As connecting an SHPP to the distribution network is not a technically demanding job, the probability of its occurrence is relatively low.
14. *Public protests after the construction of SHPP.* The risk of public protests decreases with the transition from the construction to exploitation phases. The possibility of detecting a risk during the credit approval process is very low, except in rare cases of public protests against the planned construction of the SHPP construction if such information was available to them.
15. *Abuse of watercourses.* This is an appealing option for debtors because a decrease in the water potential may adversely impact the production of power. Thus, decreasing the free flow of the river to increase water accumulation and flow through turbines would increase the power production; however, it would degrade the environment and probably violate the regulations in the domain.
16. *Currency risk.* SHPP project finance is almost immune to the risk of changes in the exchange rate because the price of the produced power is indexed in EUR, while the payment is completed within one month of invoicing. The income from power sales is employed for credit installment payments, which are also indexed in EURs.
17. *Force majeure risk is unforeseeable*. This is due to circumstances over which the participants have no control in project finance; it exerts a negative effect on the quality of project finance. SHPP project finance is subject to the risks of natural disasters, such as earthquake, landslide, and flood risks. The risk probability, as well as the possibility of its detection, are low, whereas their influence on the project is usually high. Force majeure risk is equally relevant during the realization and exploitation phases of the project.

Risk classification, as presented in Table 4, is performed, following a combined approach that was introduced by Gatti (2013) who allocated risks to the pre-completion (i.e., the construction phase) and post-completion (i.e., the exploitation phase) phases, as well as the risks common to both phases. It was also performed, following the method of Yescombe (2002) who distinguished between commercial, financial, and political risks.

5.2. Data collection and the application of the proposed method

This study relied on expert judgments to evaluate the risk events owing to the rather limited research on the inherent risks associated with the financing of SHPP projects. This study was conducted in Serbia, and experts were selected based on their expertise in the credit risk management of SHPP project finance. The following criteria were employed to select the experts: (*i*) the experts must have a minimum of 10 years of experience as a credit risk or restructuring manager, (*ii*) such experts must at least occupy senior positions, and (*iii*) they must have excellent knowledge of the credit approval process. The information finance are presented in Table 5. The experts first evaluated the identified risk events in Section 4.1, after which they attributed the O, D, and S ratings for each event employing the ranking scales listed in Tables 1, 2, and 3, respectively.

In the first step, the unique ratings of the risk factors were modified and transformed into three adjacent rating values by applying Eq. (5). In the second step, some discernment frames were excluded from further risk assessment by conducting the abnormity test for expert opinions. The answers attributed by the experts after applying the described transformation are presented in Table 6. The discernment frames, which were excluded according to the previously defined abnormity test, were struck through with a single line. The application of the proposed abnormity test in practice means that the occurrence ratings for three items assigned by expert 1 and one item assigned by expert 2, were excluded. Both of them had been subjected to negative experiences with the occurrences of those risks for a single SHPP. This is evident for risk event 13 that is related to the fault of the distribution system operator. This risk occurs very rarely; however, the expert was involved in a single project that suffered a setback owing to a mistake that was committed by EPS. The application of the proposed rule avails a more balanced approach toward risk assessment. The same rationale is applicable to other rating factors.

The results of fusing the multisource information of S, O, and D, as well as the calculated RPNs for each risk event that was obtained via the FMEA-DST methodology (Fig. 1), are presented in Table 7. Finally, the risk events were rated via the same principle, that is, a higher RPN value implies a higher rating for the risk events.

5.3. Sensitivity analysis

By assigning weights to the experts, a sensitivity analysis was performed, following the five additional cases that are presented in Table 8. Further, the results of the proposed approach and the conventional FMEA one were compared by assuming that each expert would attribute a rating with an assigned highest mass function if unique ratings were required. Following the approach of Tang et al. (2018) who employed exponential weighting to calculate the weighted RPN, the combinatorial rule for the sensitivity analysis was modified, as follows:

$$m_i^j(k) = \begin{cases} \frac{1}{1-K_i}\prod_{l\in L}\left(m_{il}^j(k)\right)^{w_i} & k \in \bigcap_{l\in L}\Theta_{il}^j \\ 0 & otherwise \end{cases}, \tag{10}$$

where $K_i = \sum_{(\exists\vartheta,u\in L)k_\vartheta\neq k_u}\prod_{l\in L}\left(m_{il}^j(k)\right)^{w_i}$ and $w_1 \ldots w_l$ are the non-negative weights with a sum total of 1. Given that $m_{il}^j(k) \in [0, 1]$, the weights listed in Table 8 must be considered in the

Table 4
Risk classification.

	Commercial risks	Financial risks	Political risks
Construction phase	1, 2, 3, 4, 5, 6, 7		8
Exploitation phase	9, 10, 11, 12, 13, 15		14
Risk common to both phases	17	16	

Table 5
Expert team information.

Expert	Experience (years)	Area of expertise	Financial risks
E1	10	Bachelor of Economics	Senior credit risk manager
E2	13	Bachelor of Economics	Senior restructuring and workout manager
E3	15	Bachelor of Economics, CFA	Head of credit risk management department

descending order, that is, the expert with the smallest weight was assigned the greatest significance.

Fig. 2 indicates that events 14, 9, and 10 were ranked in first, second, and third places in all the cases, respectively. Moreover, Case0, Case3, and Case5 ranked events 15 and 8 in fourth and fifth places, respectively, while Case1, Case2, and Case4 ranked them in fifth and fourth places, respectively. Events 3, 6, 7, 12, 13, 16, and 17 were ranked the same in all the cases. The remaining five risk events exhibited almost identical ranks in all the cases. The sensitivity analysis revealed the homogeneity between the proposed scenarios. Therefore, changing the weights of the experts exerted a low impact on the RPN ranking, indicating that the proposed method exhibits satisfactory robustness.

A comparison of the proposed method and the conventional FMEA one revealed that the RPN rankings were not the same. However, the lists of risk events that must be included in CIL were identical. A very different ranking was observed for events 4, 7, 12, and 13. The differences between the two methods were mainly due to the following: (*i*) the abnormity test for the expert opinions, which excludes the discernment frames from the risk managers who were either very risk-averse or risk-takers, and (*ii*) the combinatorial rule that was employed to fuse the multisource information. The rankings of events 4 and 13 were dominantly influenced by the abnormity test because the discernment frames of the risk-averse experts were excluded, thereby availing a more realistic risk assessment, as already discussed. Further, the rankings of events 7 and 12 were influenced by Dempster's combinatorial rule, which aggregates expert opinions based on their beliefs rather than by simply averaging the prevailing opinions.

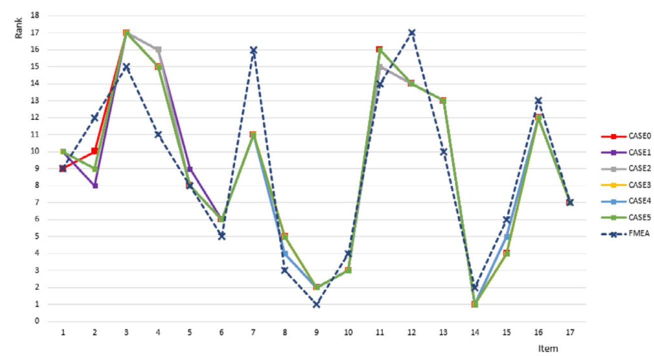

Fig. 2. Sensitivity analysis and comparison between D-S method and conventional FMEA.

6. Implications

The risk events with RPNs of ≥125 must be mitigated during the credit approval process to support credit requests whose final credit risk profiles are aligned with the creditors' risk preference. Following this approach, special attention must be paid to the following risk events: public protests against SHPP projects at the construction and exploitation phases, inadequate estimation of river potentials, seasonal fluctuations in river potentials, watercourse abuses, cost overruns during groundwork, and the force majeure risk with RPN of ∼125. These risks would be integrated into CIL. The proposed corrective actions for these events are presented in Table 9.

The findings reported here are relevant for the following reasons. First, hydropower technology is mature, thus positively contributing to the credit risk profile of SHPPs. We may expect higher risks related to equipment for other technologies, such as the geothermal and biomass technologies, that are in the early stages of their life cycles (Polzin et al., 2021). Second, effective risk-mitigating actions for certain risks, such as cost overrun and river flow potential, as proposed in this study, may be implemented without significant costs for the creditor and borrower. Third, the research results demonstrate that public opinion accounts for a very significant factor in SHPP project finance. This result is consistent with the recent findings of Mayeda and Boyd (2020) who confirmed the relevance of how the public perceives the environmental and ecological impacts of hydropower developments. Creditors must realize that financing SHPPs and other renewable energy projects goes beyond a pure credit activity and exposes them to credit risks as well as reputational risks. The creditors must pursue effective communication strategies with local and regional communities before commencing a project. Fourth, these findings have implications for policymakers in the Republic of Serbia seeking to promote investments in renewable energy projects. As indicated by Venus et al. (2020), policymakers must implement more rigorous programs to assess and monitor the ecological impacts of SHPP. The public acceptance of SHPP projects will be improved only through the strong cooperation among investors, creditors, and policymakers working together on the development of environmentally sound, socially responsible, and credit-risk-acceptable investment environment.

Table 6
Survey results.

Item	Expert 1						Expert 2						Expert 3					
	O		S		D		O		S		D		O		S		D	
1	2	40%	4	20%	~~7~~	~~80%~~	4	50%	4	15%	4	35%	3	15%	6	10%	2	60%
	3	50%	5	60%	~~8~~	~~20%~~	5	35%	5	50%	5	65%	4	70%	7	70%	3	30%
	4	10%	6	20%			6	15%	6	35%			5	15%	8	20%	4	10%
2	1	60%	6	30%	9	80%	1	60%	~~4~~	~~10%~~	9	35%	1	80%	7	80%	9	10%
	2	30%	7	40%	10	20%	2	30%	~~5~~	~~35%~~	10	65%	2	10%	8	10%	10	90%
	3	10%	8	30%			3	10%	~~6~~	~~55%~~			3	10%	9	10%		
3	~~6~~	~~40%~~	4	~~10%~~	1	30%	1	60%	7	10%	1	30%	1	80%	8	10%	1	80%
	~~7~~	~~60%~~	5	~~80%~~	2	30%	2	30%	8	35%	2	60%	2	10%	9	10%	2	15%
			6	~~10%~~	3	40%	3	10%	9	55%	3	10%	3	10%	10	80%	3	5%
4	~~6~~	~~30%~~	3	50%	~~4~~	~~30%~~	2	60%	~~6~~	~~10%~~	2	65%	3	30%	4	25%	2	15%
	~~7~~	~~40%~~	4	50%	~~5~~	~~30%~~	3	30%	~~7~~	~~35%~~	3	35%	4	60%	5	50%	3	70%
	~~8~~	~~30%~~			~~6~~	~~40%~~	4	10%	~~8~~	~~55%~~			5	10%	6	25%	4	15%
5	5	10%	~~2~~	~~50%~~	4	30%	5	15%	4	40%	~~7~~	~~65%~~	3	30%	4	25%	3	70%
	6	80%	~~3~~	~~50%~~	5	30%	6	50%	5	60%	~~8~~	~~35%~~	4	60%	5	50%	4	20%
	7	10%			6	40%	7	35%					5	10%	6	25%	5	10%
6	5	50%	3	50%	~~4~~	~~30%~~	6	25%	~~5~~	~~15%~~	8	50%	5	10%	4	30%	7	10%
	6	50%	4	50%	~~5~~	~~30%~~	7	65%	~~6~~	~~50%~~	9	35%	6	80%	5	50%	8	80%
					~~6~~	~~40%~~	8	10%	~~7~~	~~35%~~	10	15%	7	10%	6	20%	9	10%
7	3	60%	2	10%	4	30%	2	60%	2	60%	~~2~~	~~40%~~	3	50%	4	25%	3	20%
	4	40%	3	80%	5	30%	3	30%	3	30%	~~3~~	~~60%~~	4	50%	5	50%	4	70%
			4	10%	6	40%	4	10%	4	10%					6	25%	5	10%
8	9	60%	9	50%	~~9~~	~~10%~~	8	60%	9	40%	2	40%	~~6~~	~~25%~~	9	20%	2	80%
	10	40%	10	50%	~~10~~	~~90%~~	9	30%	10	60%	3	60%	~~7~~	~~50%~~	10	80%	3	10%
							10	10%					~~8~~	~~25%~~			4	10%
9	~~8~~	~~30%~~	5	30%	~~9~~	~~10%~~	5	20%	5	20%	6	60%	6	50%	7	30%	6	10%
	~~9~~	~~30%~~	6	30%	~~10~~	~~90%~~	6	50%	6	30%	7	40%	7	50%	8	60%	7	80%
	~~10~~	~~40%~~	7	40%			7	30%	7	50%					9	10%	8	10%
10	6	60%	4	10%	7	10%	6	20%	4	50%	~~6~~	~~60%~~	4	60%	~~7~~	~~30%~~	8	80%
	7	40%	5	80%	8	80%	7	50%	5	30%	~~7~~	~~40%~~	5	30%	~~8~~	~~60%~~	9	10%
			6	10%	9	10%	8	30%	6	20%			6	10%	~~9~~	~~10%~~	10	10%
11	~~5~~	~~50%~~	7	60%	~~4~~	~~60%~~	1	60%	6	30%	2	50%	2	15%	7	20%	1	10%
	~~6~~	~~40%~~	8	40%	~~5~~	~~40%~~	2	40%	7	50%	3	30%	3	70%	8	70%	2	80%
	~~7~~	~~10%~~							8	20%	4	20%	4	15%	9	10%	3	10%
12	1	10%	8	60%	3	10%	1	70%	8	10%	3	20%	1	80%	8	10%	1	10%
	2	80%	9	40%	4	80%	2	30%	9	80%	4	30%	2	20%	9	80%	2	10%
	3	10%			5	10%			10	10%	5	50%			10	10%	3	80%
13	2	50%	5	60%	4	50%	~~6~~	~~30%~~	4	20%	~~6~~	~~20%~~	1	10%	~~8~~	~~60%~~	1	10%
	3	50%	6	40%	5	50%	~~7~~	~~50%~~	5	30%	~~7~~	~~30%~~	2	80%	~~9~~	~~30%~~	2	20%
							~~8~~	~~20%~~	6	50%	~~8~~	~~50%~~	3	10%	~~10~~	~~10%~~	3	70%
14	2	60%	8	60%	~~9~~	~~10%~~	6	30%	9	70%	7	60%	5	15%	9	20%	2	80%
	3	40%	9	40%	~~10~~	~~90%~~	7	50%	10	30%	8	40%	6	15%	10	80%	3	10%
							8	20%					7	70%			4	10%
15	3	40%	8	60%	7	40%	2	30%	9	70%	8	60%	1	30%	9	20%	6	10%
	4	30%	9	40%	8	30%	3	50%	10	30%	9	40%	2	60%	10	80%	7	80%
	5	30%			9	30%	4	20%					3	10%			8	10%
16	2	20%	2	20%	6	15%	2	30%	2	10%	5	25%	1	10%	3	30%	6	10%
	3	60%	3	60%	7	70%	3	50%	3	80%	6	50%	2	80%	4	70%	7	80%
	4	20%	4	20%	8	15%	4	20%	4	10%	7	25%	3	10%			8	10%
17	1	10%	7	10%	6	50%	2	10%	9	10%	6	10%	1	10%	7	10%	5	10%
	2	80%	8	80%	7	50%	3	80%	10	90%	7	90%	2	80%	8	70%	6	80%
	3	10%	9	10%			4	10%					3	10%	9	20%	7	10%

Table 7
The results of FMEA-DST methodology and ranks of risk events.

Item	K_o	RPN_O^j	K_S	RPN_S^j	K_D	RPN_D^j	RPN^j	Rank
1	0,9650	4,0000	0,9930	6,0000	0,9650	4,0000	96,0000	9
2	0,7020	1,0369	0,6500	7,0857	0,8550	9,8069	72,0539	10
3	0,4800	1,0962	0,9100	8,6111	0,8990	1,3069	12,3363	17
4	0,8500	3,4000	0,8750	4,0000	0,6575	2,7153	36,9285	15
5	0,9985	5,0000	0,6000	4,7500	0,9100	4,3333	102,9167	8
6	0,9000	6,0000	0,6000	3,6250	0,5650	8,0805	175,7500	6
7	0,8900	3,1818	0,9975	4,0000	0,7600	4,1250	52,5000	11
8	0,7800	9,1818	0,7200	9,8517	0,6200	2,1579	195,3035	5
9	0,6000	6,3750	0,9400	7,0000	0,6200	6,8421	305,3289	2
10	0,9880	6,0000	0,6900	4,9032	0,3500	8,0154	235,8074	3
11	0,9400	2,0000	0,8840	7,4828	0,5700	2,0698	30,9751	16
12	0,8960	1,4615	0,7380	8,9771	0,9980	3,0000	39,3611	14
13	0,5500	2,1111	0,6200	5,5263	0,9500	4,0000	46,6667	13
14	0,6050	6,8861	0,9440	9,0000	0,4800	7,0769	438,5901	1
15	0,9800	3,0000	0,9760	9,0000	0,9820	8,0000	216,0000	4
16	0,9220	2,3846	0,8420	3,0886	0,8525	6,9429	51,1825	12
17	0,9280	2,1111	0,9980	9,0000	0,9200	6,5000	123,5000	7

Table 8
Weights of experts in different cases.

Case	E1	E2	E3
CASE1	0,70	0,20	0,10
CASE2	0,50	0,30	0,20
CASE3	0,30	0,20	0,50
CASE4	0,10	0,60	0,30
CASE5	0,40	0,15	0,45

7. Conclusions

This study represents the first application of the FMEA-DST methodology in the credit risk assessment of SHPP project finance from the creditors' perspective with the specific aim of ranking the risk events to determine their impacts on the overall SHPP credit risk profile. The results of this research demonstrate that the negative impact of SHPPs on the environment must be carefully analyzed and managed, so that necessary measures can be taken to minimize it and prevent negative public sentiment against this type of project. SHPPs are considered environmentally friendly only if they are constructed in the right places and in line with national legislation that meets the objectives of environmental preservation. To significantly increase the contribution of SHPPs to electricity production in Serbia, the following recommendations are offered:

- Updating the national legislation with the highest standards in the area of environmental protection. SHPPs must not be constructed in protected areas, and the projects sites in protected areas must be blocked before commencement.
- Communication and cooperation between investors, creditors, and the government must be strengthened to create an investment environment that supports SHPP development. The government must be aware of the risks associated with project finance because some of them cannot be successfully managed without government support (e.g., the environmental risk and risk of incomplete documentation).
- The improvement of the public awareness on the importance of SHPPs for the utilization of RES through improved citizenry education and the promotion of successful projects.

Furthermore, creditors must implement effective corrective actions against identified risks that may be successfully managed solely from their side (e.g., cost overrun and seasonal fluctuations in river potentials). Finally, credit risk professionals must be open to new risk-management techniques that may positively contribute to the quality of the final credit-risk decision.

However, this study is associated with limitations, but these limitations indicate directions for future research. First, the relatively simple but scientifically sound FMEA-DST approach that was utilized might positively contribute to the methodology acceptance in the new area of application, although it suffered drawbacks, such as: (i) the proposed approach to exclude some experts' assessments might be rigid when assessing risk factors, and (ii) the risk factors in the calculation of RPN are equally relevant. To address these shortcomings, the application of the existing FMEA approach or the development of other improved FMEA-DST approaches might positively contribute to the quality of the research results. Second, this study only analyzed SHPP projects. Future research must analyze the similarities and differences in the risks associated with the project finance of different RESs. Third, it would be interesting to examine the nexus between risk events because the FMEA-DST methodology examines risk events independently. Fourth, other groups of risk assessment models can be applied to validate the results of the proposed FMEA-DST model.

CRediT authorship contribution statement

Zeljko Spasenic: Conceptualization, Methodology, Formal analysis, Resources, Data curation, Writing – original draft, Writing – review & editing. **Dragana Makajic-Nikolic:** Conceptualization, Methodology, Formal analysis, Writing – review & editing. **Sladjana Benkovic:** Methodology, Validation, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table 9
Proposed corrective actions for critical items.

Item	Description	Proposed corrective actions
6	Cost overrun-groundworks	Cash collateral (or cash equivalent acceptable to Creditor) as a percentage of the total project budget that serves as a guarantee that the investor will cover any cost overrun during construction phase. Cash collateral may be released when the construction of SHPP is finished. Another effective strategy may be a turnkey agreement that transfers construction risk to the contractor (construction company) on the basis of a fixed price contract. Creditor should previously analyze the credit risk of a general contractor according to standard credit risk procedures for corporate clients.
8	Public protests during construction phase	Creditor must not finance SHPP development in protected areas. Creditor should ensure strict control of project compliance with environmental regulations during all phases of project realization. Creditors should jointly insist on clear regulations in the field of SHPP construction. The local community must be educated about the benefits of renewable energy and informed about the SHPP that is going to be constructed there. Creditor should promote positive examples of SHPP project financing in its portfolio.
9	Overestimation of river potential	Creditor should insist on historical data for river flow potential on the microlocation where the SHPP is planned. Contreras et al. (2020) showed that that climate forecasts provide useful information for the exploitation of available water resources.
10	Seasonal fluctuations in river potential	Irregular loan repayment plan and/or cash accumulation during favorable months and its consumption for loan repayment when needed. Cash collateral for this purpose should be regularly replenished to the initially contracted value. Debtor repayment capacity should be monitored quarterly, or more frequently if needed.
14	Watercourse abuse	Creditor should cooperate exclusively with trustworthy investors whose business history confirms zero conflicts with environmental regulations. Creditor should secure regular on-site monitoring of SHPP operations. This may be done by an external competent body or by internal experts employed by the bank.
15	Public protests during exploitation phase	Creditors should insist on green power certification processes. The certification process should be done by an independent competent body that awards certificates to SHPP. Those certificates should confirm that the SHPP has no harmful impact on the environment. Certificates should be regularly renewed. Until this process is in place, Creditor should secure support for SHPP development from the general public at an early stage of the project finance deal.
17	Force majeure risk	Project design should clearly address force majeure risks (for instance, flood, landslide, and earthquake). The complete SHPP, pipeline and equipment should be insured against force majeure risks.

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Zeljko Spasenic is a Ph.D. candidate and Teaching Assistant at the Faculty of Organizational Sciences, University of Belgrade. His research interests are related to corporate finance, business analytics, project finance, and credit risk management. Prior to the Faculty of Organizational Sciences, he worked as a risk manager in Erste Bank, UniCredit Bank, and Societe Generale Bank. He has experience as a credit risk manager overseeing structure finance deals, project finance deals, and the financing of renewable energy sources.

Dragana Makajic-Nikolic is an Associate Professor at the Faculty of Organizational Sciences, University of Belgrade. Her research interests are related to operation research, reliability and risk analysis, business analysis, petri nets, and business process simulation. She is the author or co-author of over 100 scientific papers and two books in Operation Research. She has been involved in several research projects.

Sladjana Benkovic is a Full Professor at the Faculty of Organizational Sciences, University of Belgrade. She is involved in numerous international scientific and research projects in financial management and business administration within higher education. She is also part of the evaluation process of the Serbian higher education institutions programme and an external evaluator for the European higher education institutions programme.