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The Use of Prospect Theory for Energy Sustainable Industry 4.0

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Abstract: Industry 4.0 challenges facilities entrepreneurs to be competitive in the market in terms of energy by rational decision making. The goal of the paper is aimed at introducing Prospect Theory (PT) in Industry 4.0 for making decisions in order to select an optimal energy technology. To reach this goal, an approach for decision making on energy investment has been developed. In this paper, the authors have also provided a new opportunity to apply the new decision making method for strengthening Industry 4.0 by addressing energy concerns based on which rational decisions have been made. The study uses a fuzzy analytical hierarchy process for weighting the evaluation sub-criteria of energy technologies and a modified PT for making decisions related to the selection of one of the investigated technologies. The results show that it is possible to implement PT in Industry 4.0 via a decision making model for energy sustainability. Decision probability was achieved using a behavioral approach akin to Cumulative Prospect Theory (CPT) for the considered technology options. More specifically, the probability has created the same threshold-based decision possibilities. The authors used the case study method based on a company located in North America which produces hardwood lumber. The company uses a heating system containing natural gas-fired boilers. This study has also contributed to the literature on energy sustainable Industry 4.0 by demonstrating a new phenomenon/paradigm for energy sustainability-based Industry 4.0 through using PT. In this context, the main motivation of writing the article has been to promote energy sustainability via complex mechanisms and systems that involve interrelated functions.

Keywords: energy efficiency; sustainability; Industry 4.0; Prospect Theory; Cumulative Prospect Theory (CPT); technology; energy industry

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1. Introduction

Challenges faced by stakeholders and the awareness of social and environmental issues and uncertainty are factors that change the way business is done in economic activity. These challenges are the impulse for making decisions under uncertain conditions in Industry 4.0 (I4.0) [1,2]. I4.0 refers to many IT issues combining engineering, information technology and management knowledge. Technological advancements in line with advanced IT-based development and sustainability correspond to the emergence of new business models using artificial intelligence. Because energy is an inherent asset in the development of Industry 4.0 for building the smart factories of the future, many energy-related decisions therefore involve risk and uncertainty. Energy consumption is being radically changed by Industry 4.0 technologies [3]. While Industry 4.0 promises many opportunities for economic development, its far-reaching impacts are largely uncertain [4]. Although manufacturing processes still need labor, advanced technology improves energy efficiency, ensures continuity, and optimizes costs in end-to-end production or chain. Cogeneration systems have been proven to be a more efficient energy technology than other recommended technologies, reducing cost and energy sources. This has been verified thanks to energy audits performed by one of the authors in the USA (Michigan State). There is a reason so much attention is paid to energy management in facilities using various high energy-intensive technologies. In the era of Industry 4.0, there are also concerns about how to reduce energy consumption, minimize CO_2 and have cost savings to enhance energy efficiency and minimize disruptions with regards to I4.0 technologies. These concerns also address how to make a rational decision in order to assess and choose the right energy technology according to sustainability principles [5]. While the fourth industrial revolution offers many opportunities for sustainability (dealing with social, economic, and environmental challenges), its impact related to energy is largely uncertain (e.g., lack of energy access) [6]. For this reason, Industry 4.0 has led to a situation in which companies, in order to gain an effective competitive advantage need to make right decisions by ensuring reliability, quality, manageability and energy availability as well as stay ahead of the competition. Each decision carries a certain amount of risk, "but some decisions are much riskier than others" [7]. Risk taking decisions have been studied for decades [8–10] because a central feature of the decision making process is risk. One of the approaches, called Prospect Theory (PT), was introduced by Kahneman and Tversky [11] and is perceived as a highly influential descriptive model of decision making in situations of risk.

Its central finding is that an individual's attitude toward risk depends on whether they face losses or gains [12] and how risk taking decisions differ from the predictions of normative models [13,14]. This is called *risk/loss aversion,* which means that people prefer outcomes with low uncertainty to those outcomes with high uncertainty, even if the average outcome of the latter is equal to or higher in monetary value than the more certain outcome [15]. Risk/loss aversion has been also used to explain the *endowment effect* [16] which means that people place a greater value on things once they have established ownership, usually items with symbolic, experiential, or emotional significance. In this context, this theory as the key factor in a behavioral model for enterprises' competitiveness will be studied in this paper.

The objective of this paper is to examine the possibility of applying PT with fuzzy AHP methods within Industry 4.0 to provide decisions-making with respect to energy efficient investment. This can be achieved by the use of a fuzzy analytical hierarchy process (fuzzy AHP) for weighting the evaluation sub-criteria of energy technologies and a modified PT for making decisions related to the selection of one of the investigated technologies. Three options of energy technologies are considered. The authors will try to demonstrate the significance of the theory, which is based on a subjective perception of values relative to a certain point of reference [11].

Although PT has been continually developing since its invention [17] and has been broadly analyzed in various sectors such as IT [18], transportation [19] services [20], health issues [21], and has been particularly influential in the fields of economics [22], psychology [23], sociology [24], etc., there is a little evidence on PT in the energy sector [25] or in the energy sustainability field (Figure 1). Some research (bibliometric analysis) has been done on the subject of "Sustainable Industry 4.0" [26] but it has not considered energy issues for assessing technologies. There is still great potential for renewable energy technologies following natural gas [27].

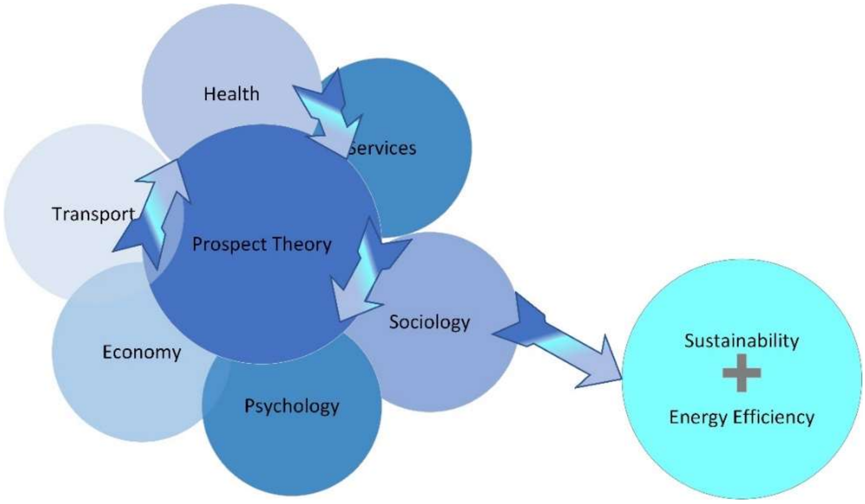

Figure 1. Studies on relationships with Prospect Theory.

Moreover, up until now, PT has not been considered in Industry 4.0, especially in the energy field. Hence, there is an opportunity to discuss the challenge in a structured way by examining an industrial case study. A decision making process has been framed within energy sustainability-based Industry 4.0 working in a situation of uncertainty. Therefore, Energy Sustainable-based Industry 4.0 has been mapped into three dimensions: environmental, socioeconomic, and technical. The energy sector (including energy systems, energy efficient infrastructure) exposes critical areas for improvement in order to make possible actions based on decision scenarios. Thus, the research attempts to fill in this gap by presenting a decision making model in Industry 4.0 with a focus on environmental, socioeconomic, and technical sustainability in the context of energy (Figure 2).

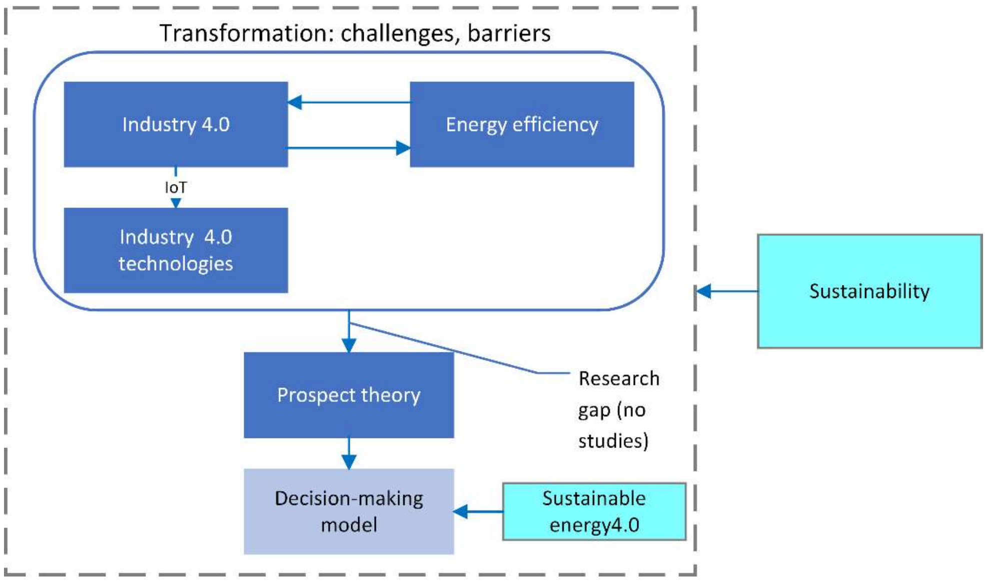

Figure 2. The link between Industry 4.0, Energy efficiency and sustainability–literature research gap.

At the same time, despite the fact that Industry 4.0 has been addressed in various contexts in much of the previous research [28,29], this paper has contributed to the literature on Industry 4.0 by presenting a new phenomenon/paradigm for energy sustainability-based Industry 4.0 (Energy 4.0 for short) that demonstrates PT in the decision making process. By applying PT in Energy 4.0, the authors have created a new opportunity to introduce a decision making method in situations of uncertainty into Industry 4.0 for the purposes of selecting the most efficient cogeneration system for a manufacturing company.

In light of the presented literature review/discussion above, the authors have proposed the following research questions:

RQ1: How does one employ PT in the context of energy technology within Industry 4.0 for the purpose of achieving energy sustainability?

RQ2: How does one make a rational decision to choose an optimal energy technology (cogeneration system)?

In the era of Industry 4.0, there is also concern about how to reduce energy consumption, ensure CO_2 minimization and cost savings in oder to enhance energy efficiency and minimize disruptions with regards to I4.0 technologies. This concern is also aimed at how to make a rational decision to choose the right energy technology. Figure 2 provides a framework for establishing the findings from the literature presented in Section 2. Understanding the interactions of Industry 4.0, sustainability and energy efficiency is a cutting-edge research topic. The present study aims to contribute to this research by explaining how Industry 4.0 may contribute to energy sustainability from decision making point of view using the PT.

For this study, a single cogeneration technology which deals with Industry 4.0 was selected. This technology is equipped with various sensors to measure and collect data from production.

Although Industry 4.0 incorporates many technologies related to sustainability based on economic, environmental, and social aspects (such as Cyber-Physical Systems, Sensors, Big Data, Simulation, Internet of Things etc.), Nara et al. (2020) [30] discussed in their article that this cogeneration technology can be treated and assessed individually due to its customizability by adding various devices and intelligent applications to measure more precisely the energy used. Through the selection and improvement of this large-scale infrastructural energy technology, it is possible to reduce the impact on the environment through a more precise measurement of the energy used, while also improving economic performance. In this way, the control over energy provides the opportunity for recovering energy, which in turn allows for highly efficient production, as well as supporting economic and environmental sustainability. In this way, the sustainability dimensions also support each other. The implication of PT for Industry 4.0 in order to make a rational decision is shown based on energy technologies. In this case, three options for a cogeneration system (combined heat and power technology) will be considered. This paper intends to apply a behavioral approach with multi-criteria decision making (MDCA) methods.

2. Literature Review

2.1. Industry 4.0 Applications for Energy Sustainability as Energy 4.0

Although Industry 4.0 applications for energy sustainability is an area of increased interest and has been gaining more and more attention worldwide [31,32], information concerning the implementation of Energy 4.0 (a. o.: Energy Cloud, Cloud-based energy management) is scarcely available in the scientific literature. In this context, this article tries to provide evidence of whether energy contributes to the scope of Industry 4.0 in general. It is worth emphasizing that Industry 4.0 is transforming manufacturing business models into those more conducive to sustainability [33] or energy sustainability. Industry 4.0 is not limited to Internet of Things or Big Data [29], but in the context of energy efficiency [34] it can also potentially provide growth in competitiveness as well as improve the sustainability of the industrial system [35–37]. Along with technological development, energy efficiency follows on the structural transformation of various branches or sectors (manufacturing, production, different energy sources such as renewable, photovoltaic, etc.) generally focused on sustainable development. Energy supply is becoming increasingly with digital sensors, while also becoming more decentralized with energy coming from a microgrid system. Thanks to this, potential users will have even more control and ability to manage their energy usage. Therefore, the concept implications on organizations' sustainability objectives requires more attention and discussion [38,39]. The fourth industrial revolution can address many of the ecological limitations of traditional industrial practices in providing sustainable development [40]. With regards to Industry 4.0, energy management is not only considered a system according to ISO 50001:2015, but also as a driver to ensure the reliability and energy availability of new applications. Moreover, energy management is critical for economic success and environmental security since energy is connected to numerous sectors of life (e.g., education, health, manufacturing, etc. [41]. According to Sanchéz-Durán et al., Industry 4.0 must address the following issues [42]:

- energy security (consistency of energy infrastructure, and capability of energy suppliers to fulfill present and upcoming demand),
- energy equity (availability and affordability of energy supply for the population),
- environmental sustainability (energy productivity and the improvement of energy provided by renewable and other low-carbon sources).

Undoubtedly, excessive consumption of energy has damaging consequences for the environment (especially through an increased carbon footprint, increased risk of climate change, or higher energy costs), as well as a heavy impact on economic growth and social inequality [41]. This impact can be measured using energy efficiency measures. Therefore, Energy Industry 4.0 could be an optimal solution for economic, environmental and social reasons by providing energy and non-energy benefits [43].

A review of research (presented in Table 1) has been conducted in various fields of studies (clusters) from the perspective of the aspects analyzed in this paper, such as: Industry 4.0, Sustainability, and Energy 4.0.

Table 1. Industry 4.0, Sustainability, Energy 4.0–clusters summary of the selected studies.

Research Category/Cluster	Research Areas/Content Analysis	Source
Industry 4.0	Analysis of Industry 4.0 from the perspective of the circular economy, and grounding economic governance, as well as from a complex point of view;	[38,44–47]
	Analysis of problematic Industry 4.0 in relation to management and IT operations;	[48–50]
	Role of Industry 4.0 in transportation research;	[51,52]
	Analysis of social environment from the Industry 4.0 perspective;	[53]
Sustainability	Analysis of energy efficiency trends in the context of sustainability;	[54–57]
	Focus on sustainable economic development;	[58]
	Research conducted in the field of sustainable manufacturing;	[59,60]
Energy 4.0	Reviewed the literature on renewable energy and coal	[61,62]
	Impact of harvested energy on battery life and the deployed sensing interval of LoRa motes across production facility	[63]
	Analysis of the future situation for global energy development taking into account the history of energy use and energy sources	[64]

As is presented in the table above, much research concerning Industry 4.0, sustainability as well as energy efficiency has been conducted in various fields of studies all over the world. It is worth emphasizing that these analyses have many uses, common approaches and aims. Sustainability problematic is essential both in economy, manufacturing, and energy industry as well as in transportation.

2.2. Prospect Theory in Decision Making in Energy 4.0

Despite the deepening analysis concerning Industry 4.0 and its significance, few studies have paid enough attention to PT in Industry 4.0 sustainability, even though Industry

4.0 has the potential to dramatically influence social and environmentally sustainable development [39]. PT has been applied in diverse areas, such as consumption choice, labor supply, and insurance [65]. There is also significant lack of knowledge and uncertainty about the relationship between sustainability and Industry 4.0 [66]. Evaluating its impact, importance, as well as the relationship between Industry 4.0 and sustainability may be difficult but it is still an important subject of research on making an optimal decision. Business and industrial organizations have been trying to seek various solutions and methods to respond to global pressure regarding corporate social responsibility [67]. Similarly, the authors have attempted to apply PT with broader Industry 4.0 implications in mind. Many complex methods for supporting decision making process have typically been used in economic settings relying on different configurations such as: (1) Best Worst Model (BWM), an integrated BWM with Cumulative Prospect Theory (CPT) (CPT + BWM) [68], and with geographical information system (GIS) + Best Worst Model [(GIS + BWM)] [69] for selecting power plants projects; (2) decisional methods such as: decision trees, linear programming, multicriterial programming, game theory or procedure of analytical hierarchization. All particulars concerning decision making process and its models, methods as well as strategies that have been used in many research areas could be also applied in energy sustainability for Industry 4.0 (as presented in Table 2).

Table 2. Literature analysis—models, methods and strategies in decision-making process.

	Models	Source	Methods	Source	Strategies	Source
Decision making process	Rational model	[70,71]	Decision tree	[72,73]	Dominance strategy	[71,74]
	Bounded rationality model	[75,76]	Linear programming	[77,78]	Lexicographical strategy	[79,80]
	Vroom-Yetton model	[81]	Multicriterial programming	[82,83]	Diagnosis strategy	[84–86]
	Multi-criteria decision making (MCDA) model	[87–89]	Game Theory	[90,91]		
	Recognition-primed model	No sources (research gap)	Procedure of analytical hierarchization	[92,93]		
			CPT + fuzzy AHP framed in I4.0	the Authors		

Because of this paper's limitations, the authors have chosen a decision tree method whose purpose during the decision making process is to simplify the assessment of situational decisions. The model enables one to analyze many decisional variants (choice alternatives) and their assessment criteria at the same time [94]. The decision tree is used in risk assessment to make a choice of the optimal solution in situations of uncertainty. Moreover, additional odds and costs of separate decisional variants lead to increase of optimization rationality through maximization of expected utility focused on maximization of effects [95]. The opposite and alternative theory (PT) consists of two decisional phases: (1) the editing (or framing) phase, which encompasses what are widely known as framing effects; this is the analysis of decision's situation, results' coding, simplifying, separating, and avoiding; (2) the assessment phase (values function and weights function) involves the decision process of choosing among options; it is about value assessment, while chances assessment runs contrary to Expected Utility Hypothesis [96,97], which says that people do not make optimal and rational choices.

Additionally, in the expected utility approach to decision making under risk, the utility of a risky prospect is given by the sum of the utilities of the alternative possible outcomes of the prospect, each weighted by the probability that the outcome will occur [96]. Concerning the characteristics of decision trees PT (based on psychophysical models) seems to be successfully applicable to the decision making process but the researchers point out that the results can occur quite different (from optimal) because of the reference point (a critical concept in assessing gains and losses), which is characteristic feature in PT and the points differ depending on who makes decisions.

With regard to the idea of PT presented above, one can say that the energy industry could benefit from consideration of behavior [98,99]. However, methods that take realistic rational decision rules into account have little impact on the dynamics of energy Industry 4.0 implementation. The presented paper offers a new perspective on energy sustainability analysis with PT. Although the decisions concerning various ways of energy industry development and deployment are influenced by many factors, the proposed approach can reproduce most of the dynamics of the uptake with only a few behavioral assumptions.

None of these were used in the context of energy efficiency and it should be high on the priority list and in the investment projects of facilities. Due to the high potential of PT, it seems to be realistic to apply it in Industry 4.0 for evaluating energy technology in terms of sustainability.

The relationship between Industry 4.0 technology, energy efficiency and sustainability are sketched in detail in Figure 3, where the relationships are described as follows:

(1) some decisions are made under uncertainty (e.g., through the use of high volumes of data), and some of them lead to challenges. Both generate the risk in Industry 4.0;
(2) risk influences Industry 4.0 through digital networking and associated IT security;
(3) industry 4.0 supports and develops further technologies such as energy technologies
(4) established energy technologies influence the energy sustainability concept;
(5) energy I4.0 technology applied to (Energy) Sustainability causes different effects/outcomes in terms of different performance dimensions;
(6) the effect of the I4.0 interventions is measured and evaluated based on which decisions are made.

The changes have an impact on the integration of the decision making model, Industry 4.0 technologies and energy sustainability facilitate the Sustainable Energy 4.0 paradigm implementation.

Considering these interdependencies between the components of the Energy 4.0 paradigm (Energy Sustainability–based Industry 4.0), Figure 3 thus complements the identified research gap in Figure 2.

Nevertheless, an integration of energy efficiency, sustainability and PT in decision making is still poorly developed for supporting and moderating decisions.

To the best of the authors' knowledge, the major contributions can be stated as follows:

- The application of PT to make a decision in the selection of energy investment under a certain risk;
- The decisional problem focuses on the aggregated level of data against three scenarios of energy technologies to be implemented;
- The approach encompasses economic, social, environmental and other relevant considerations (technical), not treated within the definition of energy sustainability.

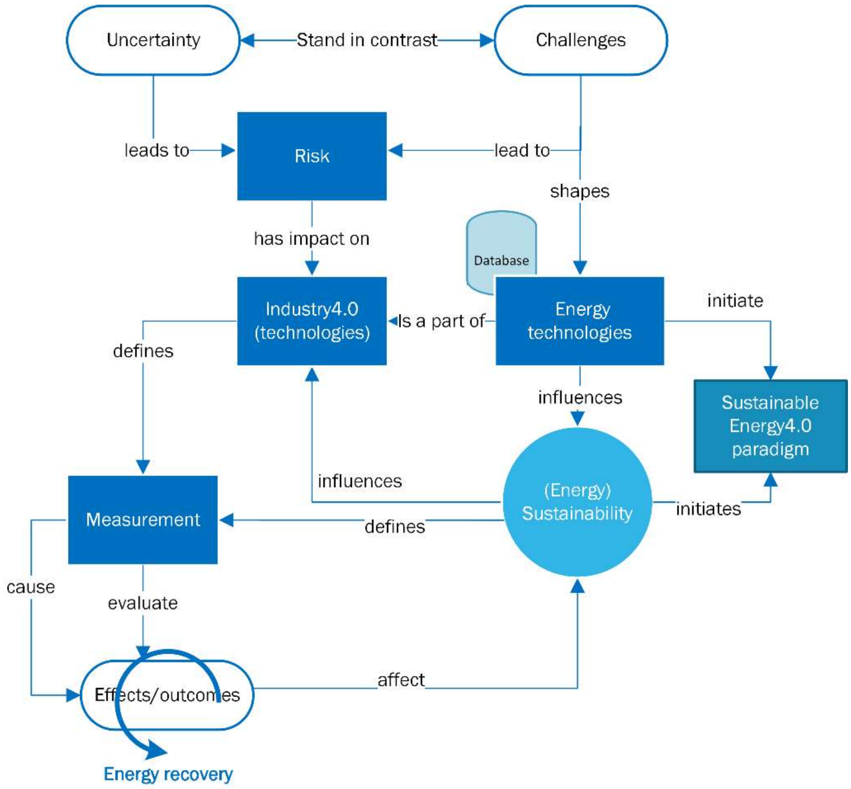

Figure 3. Relationships network.

3. Materials and Methods

In this paper, the authors used the methodology for the multi-criteria decision making problem, which consists of the following stages, as presented in Figure 4:

1. Problem and opportunities statement on the basis of literature review;
2. Selection of assessment criteria and sub-criteria on the basis of an energy data inventory and literature review for evaluation of energy technology;
3. Formulation of energy technology options/alternatives to be evaluated from the sustainability perspective for Industry 4.0;
4. Building the decision tree:
   - 4.1. Expert evaluation of the sub-criteria in terms of energy technologies by assigning weights for each sub-criteria using fuzzy AHP;
   - 4.2. Application of the multi-criteria method. In this stage, the optimal decision making process concerning selection of energy technology based on CPT is performed. This phase consists of two sub-stages: (1) identification of outcomes for the four sustainability dimensions under cumulative prospect theory; (2) identification of probabilities for the above-mentioned outcomes. The outcomes are represented by the fuzzy AHP weights defined by three energy experts.
5. Analysis of the results and discussion.

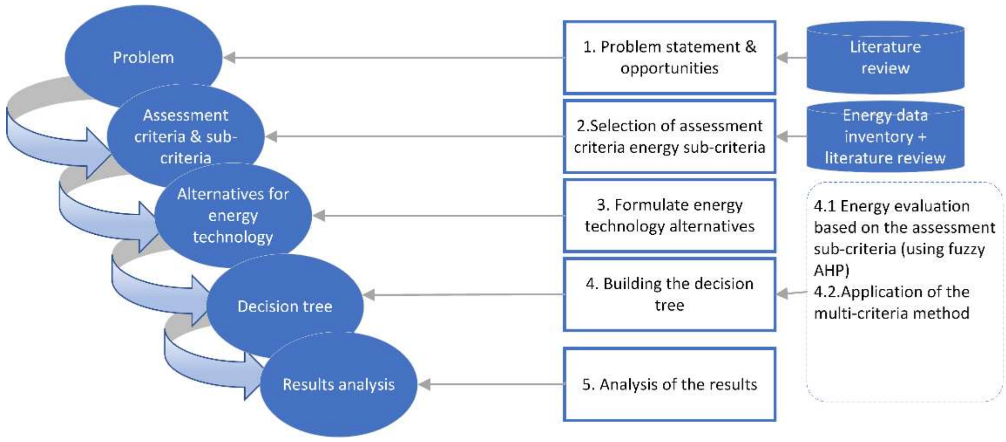

Figure 4. Adopted research methodology for implementation of PT in the implementation of energy-based Industry 4.0 technologies for sustainability.

Considering the methodology, the first phase is to determine a research problem, and determine how to solve it with the use of the selected methods and techniques, through the literature review. The next step is to select criteria and sub-criteria with respect to the energy technology evaluated (thanks to energy data inventory). This leads to formulating energy technology alternatives (the third phase). The fourth phase is to evaluate the technologies using the fuzzy AHP method. At this stage, the weights of the sub-criteria selected are obtained. During the fourth stage of the approach, the authors create a comparison matrix of the sub-criteria used in the paper and calculated the weight values of the fuzzy set. Then the output of this is taken as input to the decision tree within the PT for defining the best technology options as the fifth phase. Finally, the decisions as results are examined and interpreted in the light of PT at the sixth stage. A description of the steps within fuzzy AHP are developed in the following subsections.

The proposed methodology consisting of two methods was chosen as an effective tool adapted to support the decision making process and make rational, appropriate decisions by users. Within the applied methodology, an evaluation of available energy technologies based on fuzzy AHP was performed. This evaluation considers the suitable sub-criteria for three cogeneration systems. Fuzzy AHP was used to solve problem of using various functional units, capturing the vagueness of the parameters, and thus providing preciseness of human judgments [100].

For the goal of this paper, the authors have focused on CPT that is used as a tool for making decisions to select the optimal variant of energy technology. It considers four sustainability dimensions. This means that the standard PT was not used in its original version, not meeting its primary role for choosing between losses and gains. A decision making process has enabled an examination of all the considered weights within the sustainability dimensions (environmental, economic, social, and technical) to define decisional variants and their consequences. The values function can also be presented in the form of the following dependencies:

$$ev = \sum_{\mathrm{i}} w(\mathrm{pi}) v(\mathrm{oi}) \tag{1}$$

where:

ev—expected values' function (scenarios);

w(pi)—decision making weights based on Hurwicz's criterion, Wald's criterion, and Savage's criterion [101];

v(oi)—values' function.

To present it in a mathematical way, CPT can be calculated as follows:

$$\mathrm{P} = \mathrm{w(p)} \times \mathrm{v(x)}, \tag{2}$$

where:

w(p) = weighted probabilities, and

v(x) = value of the potential outcome.

The outcomes have been determined for each of the three variants using a software package by Köbberling [102]. This calculator computes the value of prospects under CPT. First step involves calculating three outcomes (variants) on the basis of the parameters given by Kahneman and Tversky [103] as presented in Equations (1) and (2).

The value function (where loss aversion parameter is λ) is as follows:

$$\mathrm{v(x)} = \begin{cases} f(x) & if\ x > 0 \\ 0 & if\ x = 0 \\ \lambda * g(x) & if\ x < 0 \end{cases} \tag{3}$$

where *f(x)* and $\varrho(x)$ are defined as follows:

$$fx = \begin{cases} x^{\alpha} & if\ \alpha > 0 \\ \ln(x) & if\ \alpha = 0 \\ 1-(1+x)^{\alpha} & if\ \alpha < 0 \end{cases} \text{ and } gx = \begin{cases} -(-x)^{\beta}\ if\ \beta > 0 \\ -\ln(-x) \text{ if } \beta = 0 \\ (1-x)^{\beta} - 1\ if\ \beta < 0 \end{cases} \tag{4}$$

where: α: 0.88 (power for gains); β: 0.88 (power for losses); λ: 2.25 (loss aversion); γ: 0.61 (probability weighting parameter for gains); δ: 0.69 (probability weighting parameter for losses).

4. The Implementation of Prospect Theory in Industry 4.0 for Energy Sustainability Based on a Real Case Study

4.1. Company Description

The facility, located in North America, produces hardwood lumber and operates an average of 52 weeks per year. The facility houses a total of 45 employees. The company, being in the early stages of the fourth revolution, uses partially metered electricity connected to the integrated utility systems and transfers data to a central system via the Internet. The system collects data on the consumption of all utilities. Data are hosted on a cloud-based system. These data are analyzed online and the company receives a set covering current use of utilities (energy, gas, heat, compressed air), which is used to determine future costs and energy savings. Most energy is consumed by an electrical cutter and planer, grading machines, lighting, boiler, and facility heating. This facility tends to optimize its lifetime costs, proving willing to be a leader in energy saving through the application of IoT energy metering. In the future, the industrial plant intends to apply Big Data processing technologies.

4.2. Energy Technology Profil

The industrial plant uses a heating system containing two natural gas-fired boilers. The boilers can operate up to 150 pounds per square inch in gauge (high pressure), and the second boiler is used as a backup. The energy is transferred from the boiler to the turbine through high pressure steam that in turn powers the turbine and generator. The generator heats up when it produces electricity. The planned cogeneration system (CHP) will capture this heat and use it to regulate heated water. In the CHP system, steam at lower pressure is either extracted from the steam turbine and used directly or it is converted to other forms of thermal energy.

4.3. Potential Technological Solution through Digital Transformation

One of the recommendations from the energy audits performed by the University of Michigan Industrial Assessment Center experts (UM IAC) has been to save electricity in the plant by installing a cogeneration system. The energy experts have proposed with their assessment three variants of CHP systems based on the factors of energy savings (\$/yr), estimated savings (\$/yr), and implementation cost (\$). Additionally, each assessment recommendation covers the installation of software capable of centralizing the input of data from the areas of the plant and making it available to other areas in real time. Variant VIII is the most highly recommended by the three-person UM IAC team.

The cogeneration system will use natural gas to generate electricity. Steam will be directed into a step-down turbine for the heating system, to reduce pressure and to generate power, all at the same time. The turbine generates the electricity, and the exhaust steam from the turbine will be a supplied process (as shown in Figure 5).

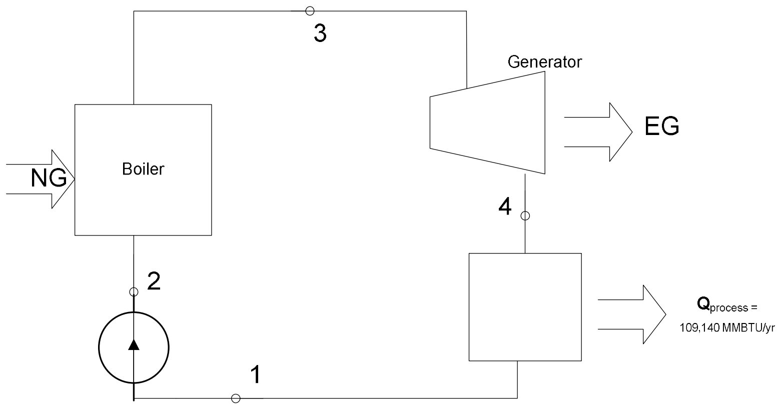

Figure 5. Model of the cogeneration system.

4.3.1. Problem Statement

The problem has been identified in the Introduction section as a lack of the integration of energy efficiency, sustainability, as well as the concept of Industry 4.0 and PT in the decision making process for energy sustainability-based Industry 4.0. The current literature has confirmed that the topic is still too poorly developed to fully support and moderate decisions for energy technology. This exemplary case is based on the assessment of cogeneration system (CHP) technology.

4.3.2. Data Collection and Formulation of Energy Technology Alternatives to Be Evaluated

Technical and operational data about energy technology have been gathered based on energy audits, then analyzed and processed by energy experts. The data collection and outcomes of the energy analyses resulting from the energy audits have been aggregated and presented in Table 3. The table also depicts three potential alternatives for selecting appropriate CHP technology: a step-down turbine with a 150 PSIG pressure boiler, a new boiler with 300 PSIG pressure and a new turbine, and a new boiler with 600 PSIG pressure and a new turbine. These alternatives were presented by the UM IAC experts' energy assessment of the plant's manufacturing processes according to energy efficiency measures and then were recommended in the energy audit report. Energy audits generally allow for analyzing energy flows for the purpose of energy savings to make industrial technology or production processes more efficient [104–107]. Based on their analysis of energy collection data and the technology recommendations outlined in the energy report, the experts have selected or defined assessment criteria and sub-criteria as presented in Tables 4 and 5. Data collection from Table 3 was a basis for identification of the subcriteria. Next, the assessment sub-criteria were divided by the authors into sustainability criteria (Table 4) based on the current literature on sustainability. In terms of the transition toward Industry 4.0, these four-dimensional criteria meet sustainable development goals as specified in many publications, e.g., in [108–110].

Table 3. Data collection and potential technology alternatives suggested by the energy experts for making decisions on the selection of an optimal energy technology (CHP).

Sub-Criteria	Calculation of Indicators Based on Energy Analysis	Technology's Alternatives to Be Applied as a Result of Recommendations Given by the Energy Experts (Gathered during Energy Audit/Assessment)		
		Variant 1	Variant 2	Variant 3
		Purchase a step-down turbine operating with a 150 PSIG pressure boiler	Purchase a new 300 PSIG pressure boiler and a new turbine	Purchase a new 600 PSIG pressure boiler and a new turbine
Natural gas usage with cogeneration NGc [MMBTU/y]	NG [MMBTU/h] × 8736;	130,166	132,787.20	134,883.84
Natural gas cost with cogeneration NGCc [$/yr]	NGCC = NG × 5.675 [gas cost in MMBTu/h]	738,694.32	753,567.36	765,465.80
Natural gas consumption compared to current consumption NGUS [MMBTu/yr]	NGUS = NGSQ − NGC	−21,026.40	−23,647.20	−25,743.84
Natural gas cost increment compared to current consumption NGCI [$/yr]	NGCI = NGCSQ − NGCC	−119,324.82	−134,197.90	−146,096.30
Generated electricity ELG [kWh/yr]	ELG = EL [kW] × 8736	2,245,152	2,865,408	3,476,928
Energy value EV [$/yr]	EV = ELG [kWh] × 0.0716 [energy cost]	160,752.88	205,163.21	248,948
Electricity demand value ED [$/yr]	ED = EL [kW] × 12 × 8.477 [cost demand]	26,143	33,365.50	40,486.15
Total electricity value (generated) EV [$/yr]	EV = EV + ED	186,896	238,528.7	289,434.15
Electricity usage EU [kWh/yr]	EU = ESQ − ELG	2,897,600	2,434,592	1,823,072
Electricity actual cost after implementation of cogeneration system ECC [$/yr]	ECC = ECSQ − Ev	323,104	271,471.33	220,565.81
Total cost savings TCu [$/yr]	TCu = (NGCSQ − NGCc) + Ev	67,571.2	104,330.84	143,337.85
Implementation cost IC [$/]	Given by energy auditors	206,250	393,600	477,600
Simple Payback SP [yr]	SP = implementation cost/annual cost savings	3 (36 months)	3.8 (45 months)	3.3 (40 months)
Greenhouse emission [tons/yr]	CO_2 equivalent; calculated using https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator (accessed on 25 October 2021)	298,801	30,401	30,881
Maturity level	Expressed in years	25	30	30
Risk of interraption	Based on scale of 1–5	4	4	4
Data acquisition	A way of typing energy data at the technology level	Some manual data entry	Some manual data entry	data entry automatically

Recommending energy savings actions is part of a large-scale plant improvement project. The company started to work on the implementation of energy technology, its upgrade and/or purchase of new technologies. From a risk perspective, operators are alerted concerning connected reliability in the energy systems via multiple systems and any failure source is monitored up the chain of command. After the installation of new boilers and the upgrade of the present installation, vendors will provide quality training programs through on-demand information systems. Mobile devices will be used to communicate alarms internally among operators. Data from processes will be collected automatically, ensuring regulatory compliance and safe operations.

Table 4. Assessment criteria of energy technology options for energy sustainability-based Industry 4.0 in terms of the four sustainability dimensions.

Environmental sustainability & benefits	– Reduction of the local impact on the environment by contributing to minimizing the negative impacts of energy technology on the environment [111]. – Focus on the implementation of renewable energy technology or the replacement of non-renewable with renewable. – Adoption of closed loop supplies of energy use, reuse – Society's increased awareness of the environmental issues in every issue of planning, operation and use phases.
Economic sustainability & benefits	– An investment in energy efficiency technology is economically sustainable if its revenue is sufficient to provide energy for its company's operations. – Management of repair and maintenance remotely for its lifespan
Social sustainability & benefits	– Focus on the equitable distribution of benefits offered by and social acceptance of electrification which can be gained by enabling the technological intervention in basic social services e.g., health, education, communication & information; which also contributes to poverty reduction by fostering income generation opportunities for the local community so that everyone irrespective of any economic, social or gender disparity can make the use of service. – Concentrates on social and technical risk [5]
Technical sustainability & benefits	– Energy focuses on the system's capacity to provide efficient and – reliable energy services throughout its economic lifespan. – Focus on the advancements of innovative IT solutions to sustainability problems to enable better use of renewable energy through grid-scale storage. – Digital energy data acquisition via interfaces from multiple controllers and machines – Provision of energy data and process information via industrial IoT for energy metering

Table 5. Identified sub-criteria and their detailed contents for evaluating energy sustainability of energy technology within Industry 4.0.

Sub-Criteria	Type of Sub-Criteria	Unit	Optimize/ Goal	Description	Reference
Energy recovery (C.2.1)	Environmental	[KWh/yr]	Maximize	The annual amount of energy generated using CHP is in the direct form of electricity, which can be effectively delivered on the market. It is a proven high energy efficiency technology which ensures low environmental impact.	
Natural gas consumption compared to current use NGCI (C.2.2)	Environmental	[$/yr]	Maximize	The annual amount of gas usage per year by CHP compared to the current gas consumption (before implementing energy efficient solutions)	[112]
Reliability of energy supply (C.4.1)	Technical	Qualitative (1–5)	Maximize	The stability, security and predictability of infrastructure of energy suppliers. Risk of interruption	[113]
Maturity of technology (C.4.2)	Technical	Qualitative (1–5)	Maximize	A state of the company's exisitng technology of that has been in use for long enough on the market (technical lifecycle in yrs)	[114]
Integrated with IT (data acquisition) (C4.3)	Technical	Qualitative (1–5)	Maximize	Connectors for energy data exchange with systems or other database. Independant and open interfaces on device level	
Investment Benefit (Profitability) (C.1.1)	Economic	[$]	Maximize	Profitability of the investment is expressed using simple payback period for implemented technical solutions (device, hardware). The project includes software investment costs of cost	[115]
Access to monitoring energy (C 4.4)	Technical	Qualitative (1–5)		Access to energy measuring and moitoring using sensors	[116]
Greenhouse emission/GHG avoided (C.2.3)	Environmental	CO_2 kg	Minimize	The amount of GHG emission avoided, expressed in CO_2 equivalent thanks to the implementation of low-carbon CHP. In other words, future contribution of CHP to mitigation of air pollution and climate change.	[117]
Total energy cost saving (C.1.2)	Economic	[$/yr]	Maximize	The total amount of estimated cost savings achieved by the industrial company as a result of energy efficient technology.	
Additional staff (C.3.1)	Social	Qualitative (1–5)	Minimize	Creation of new job positions for monitoring and servicing of hardware and software	
Risk and safety for labor efficiency (C3.2)	Socio-economic	Qualitative (1–5)	Maximize	Elimination and mitigation of potential risk. Enhanced personnel competence in order to prevent accidents; reducing technology/automated devices or facility damages; reducing inter-human contact	[118]

4.3.3. Identification of Criteria and Sub-Criteria for Assessing Energy Technology for Industry 4.0 from Energy Sustainability Perspective

Several sub-criteria needed to evaluate renewable technology were presented, including problem and fuzzy AHP method characteristics. The sub-criteria, criteria (categories) within which the sub-criteria are framed were described and sketched in Table 4. Based on the analysis of data from the energy report (Table 3), the following eleven sub-criteria to evaluate CHP technology were defined and distributed among the four equally weighted sustainability dimensions (Table 5) according to the judgment of the three energy experts.

To help understanding a logical flow between the defined criteria and sub-criteria for selection of an optimal energy technology, a hierarchical structure was depicted in Figure 6.

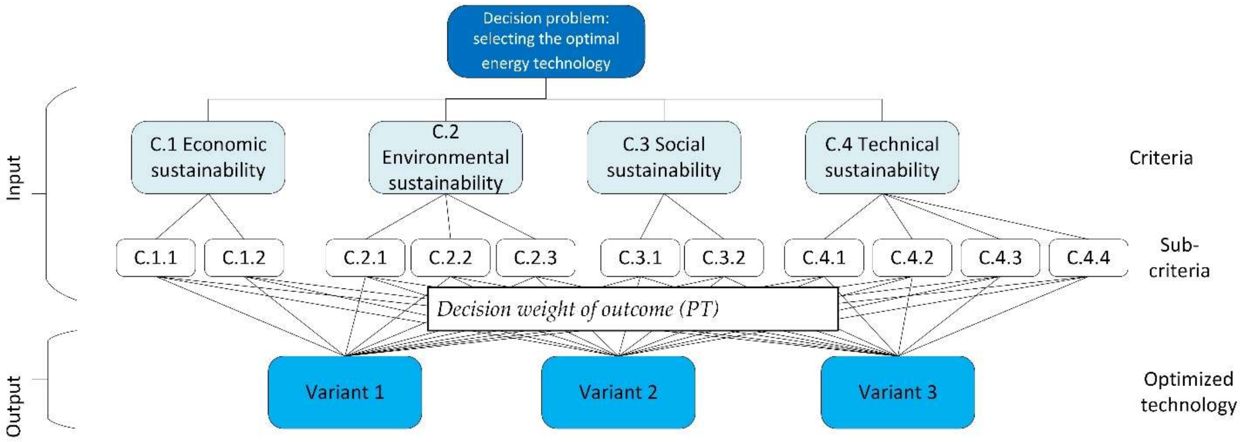

Figure 6. The hierarchy structure of the methodological approach: criteria, subcriteria and the alternatives.

4.3.4. Evaluation of Energy Technology by Assigning Weights

This phase entails identifying the individuals who would be representatives for the target population. The criterion for the selection was that the representative should be in a position to influence policy or decision making in the energy sector. A total of three specific lead participants were identified out of the group of energy auditors available at Michigan University, who had performed the energy efficiency analysis in the considered industrial plant (Names of experts and their positions are not disclosed in this paper due to the confidential reason.).

For the evaluation of the CHP technology, fuzzy AHP was applied to carry out the analysis of energy efficiency performance of three variants of cogeneration systems (energy consumption, power generation, etc.) in terms of the economic, social, environmental and technical aspects. The evaluation relies on weighting side-by-side comparisons of sub-criteria (the triangular fuzzy numbers side-by-side comparison matrix) for the technologies considered. This widely used multi-attribute decision making method was selected due to its versatility [119] for solving complex problems in various areas [120] while providing various sustainability assessment (scenarios) "adjusted to authors' expected results" [121]. With respect to the energy sector, Shaban et al. [27] used multi-criteria decision methods to select the most valuable energy technologies from among various energy sources. A multi-criteria decision approach using six criteria (availability, risk, technology, economics, environment and social) was chosen to evaluate the energy system [121]. Ulewicz et al. [122] considered the criteria of renewable energy source choice using a combination of the fuzzy analytic hierarchy process (fuzzy AHP) and the technique for preference by similarity to an ideal solution (TOPSIS). Because the sub-criteria are expressed using different functional units, the fuzzy AHP was chosen for use in this research in order to avoid bias decisions. Here it should be noted that this method does not find the best variant of energy technology, but evaluates the three variants in terms of a relative importance under the individual sub-criteria of technology.

A description of the steps within the fuzzy AHP has been developed as follows:

- Building fuzzy side-by-side comparison matrix;
- Set up Triangular Fuzzy Numbers (TFN) as (1, 3, 5, 7, 9), which will be used to consider the fuzziness of the eleven sub- criteria for energy sustainable technologies

(see Table 6). TFNs indicate the relative strength of each pair of elements in the same hierarchy. TFN as M (l,m,u) ~ = where $l \leq m \leq u$, has the triangular type membership function;
- Compute the weight value of the fuzzy vector (TFN of the sub-criteria) and the normalization of weight vectors.

Table 6. Fuzzy scale based on fundamental comparative scale [123].

Intensity of Importance Function	Fuzzy Number	Linguistic Evaluation	Triangular Fuzzy Number Membership (TFN)
1	1	Equally important	(1,1,2)
3	3	Moderately more important	(2,3,4)
5	5	Strongly more important	(4,5,6)
7	7	Very strongly more important	(6,7,8)
9	9	Extremely more important	(8,9,10)
2	2	The intermittent values between two adjacent scales	(1,2,3)
4	4		(3,4,5)
6	6		(5,6,7)
8	8		(7,8,9)

Due the length of this paper, the calculation of weights based on fuzzy theory [124], will not be presented. A detailed computation within the fuzzy AHP procedure is outlined in another paper by the authors [125].

Coming as a result of the evaluation, scores for each sub-criterion under energy technology selection have been depicted in Table 7. According to the fuzzy AHP process, results can be aggregated based on Equation (1) to obtain a final relative value for the energy sustainable technologies.

Table 7. Evaluation of technology by ranging the grouped sub-criteria using fuzzy AHP methods–evaluation scores for sub-criteria under energy technology selection.

Criteria Created Based on Type Sub-Criteria	Sub-Criteria [Units]	Fuzzy AHP (in %)	Weighted Factors Fuzzy AHP (in %)	Fuzzy AHP (in %)
		Variant 1	**Variant 2**	**Variant 3**
Economic Sustainability (C.1)	C.1.1 Investment profitability [$/yr]	3	5	6
	C.1.2 Total energy cost savings [$/yr]	3	5	6
Environmental Sustainability (C.2)	C.2.1 Energy recovery [pcs/yr]	19	19	22
	C.2.2 Natural gas consumption compared to current use NGUS [MMBTu/yr]	22	26	20
	C.2.3 Greenhouse emission avoided (GHG) [kg/yr]	4	5	4
Social Sustainability (C.3)	C.3.1 Additional staff [pers/yr]	2	3	3
	C.3.2 Safety and risk [scale 1–5]	3	2	2
Technical Sustainability (C.4)	C.4.1 Reliability of energy supply [scale 1–5]	13	14	13
	C.4.2 Maturity of energy technology [scale 1–5]	6	7	11
	C.4.3 Integrated with IT (data acquisition) [scale 1–5]	8	9	9
	C.4.4 Access to monitoring energy [scale 1–5]	8	5	5

4.3.5. Building a Decision Tree Model for Making Optimal Decisions for Energy Technology

Making optimal decisions is not as obvious as it is taken for granted in the classical economy. Therefore, the authors of this paper have also used CPT for making optimal decisions considering the emotional impact, from the behavioral point of view (as it is analyzed in behavioral economy), of the three variants/alternatives (as presented in Table 3) for selecting energy technology. For strengthening the CPT which assumes assignment subjective weights for decision scenarios based on their occurrence, the weighting of criteria (outcomes) has been calculated using fuzzy AHP. It is called "function of decision making weights" and it is said that the weights do not always suit probability (individuals with under-record medium and high probabilities, whereas they overstate low probabilities). A graphical decision tree presents consequences of potential decisions made by decision-makers (Figure 7). To complete the decision making process, the scenario method was used [126], which is one of the methods which includes many factors and their variability and presents the more or less probable variants of consequences. The method presents sequences of fluctuations of accepted values/weights which means that big fluctuations in the sequence means high risk, whereas a sequence of small fluctuations means low risk. To introduce the above method, the authors have determined the weights of the decision making scenarios using multi-criteria decision approaches (MCDA) [127] taking into consideration the four sustainability dimensions (economic, environmental, social, and technical). Then, they used the following three criteria for the decision making process (mentioned above):

- Wald's criterion–The decision maker performs the chosen decision only once and behaves cautiously; the minimal guaranteed benefit is maximized. It is a pessimistic approach to decision making;
- Hurwicz's criterion–The decision maker performs the selected plan only once and declares the level of pessimism and optimism; the optimization model only takes into consideration extreme payoffs connected with the given alternatives;
- Savage's criterion–This criterion minimalizes the expected loss by the decision maker, which comes from making a worse than optimal decision. In decision making process the strategy in which relative loss is the smallest is chosen.

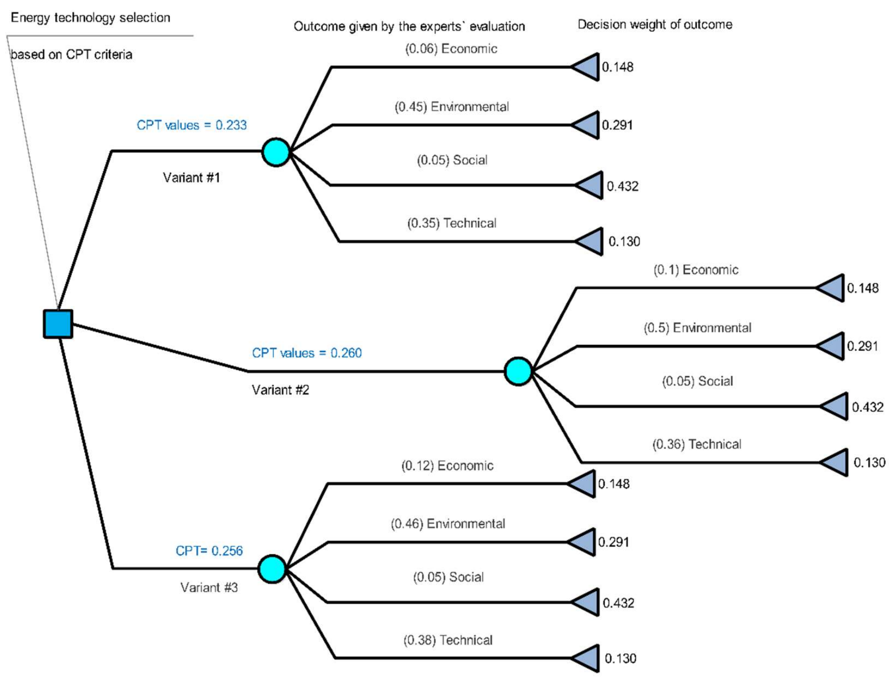

Figure 7. Decision tree.

Following the scenario's criteria, the authors of this paper asked the energy experts (who conducted the energy audits mentioned above) about their decisions concerning the three variants (see Table 3). Additionally, due to a lack of research in the area of PT in energy sector, the authors of the paper used research analysis from experimental economy area [128] and on the basis of this they have implemented the following probability ranges based on experts' knowledge as follows:

- probability 1 (low probability of risk) = 0.0–0.4;
- probability 2 (medium probability of risk) = 0.5–0.7;
- probability 3 (high probability of risk) = 0.8–1.0.

Then the authors asked participants of the research (energy experts from the UM IAC) to choose one of the three variants. The participants who answered "Variant 1", "Variant 2" or "Variant 3" were then asked again to rate the intensity of the probability ranges. According to these ranges of probabilities, Variant 1 was chosen (with probability 3, which means high probability), whereas with respect to the criteria one can say that Wald's criterion is the most appropriate to the chosen Variant 1.

5. Results and Discussion

In this step, values of outcomes represented by the criteria were calculated using fuzzy AHP weights by multiplying outcomes (environmental, economic, social and technical) by probabilities for each criterion (Table 8). The outcomes, expressed in per cent values, are represented by the sum of fuzzy AHP weights in terms of each sustainability dimension. In other words, the percentage values of sub-criteria corresponding to each sustainability dimension were summed up. The probabilities for the four outcomes to calculate the PT were assigned by the energy experts the value of 0.25. The same three energy experts (from the UM IAC, as mentioned in Section 4.3.2) who evaluated the cogeneration technology were asked to identify probabilities for the outcomes corresponding to the environmental, economic, social and technical dimensions.

Table 8. Calculation of CPT values for the energy technology variants; decision weights were calculated using http://psych.fullerton.edu/mbirnbaum/calculators/cpt_calculator.htm (accessed on 25 October 2021).

Alternatives	Variant 1		Variant 2		Variant 3	
Sustainability Criteria (Dimensions)	**Outcome (Fuzzy AHP)**	**Decision Weight of Outcome**	**Outcome (Fuzzy AHP)**	**Decision Weight of Outcome**	**Outcome (Fuzzy AHP)**	**Decision Weight of Outcome**
Economic	0.06	0.148	0.1	0.148	0.12	0.148
Environmental	0.45	0.291	0.5	0.291	0.46	0.291
Social	0.05	0.432	0.05	0.432	0.05	0.432
Technical	0.35	0.130	0.36	0.130	0.38	0.130
CPT Values	0.233		0.260		0.256	

The three experts, considering the same importance for each dimension, were consistent in assigning weights. Each dimension is just as important as the others.

Based on the CPT values, the values achieved for the three variants fall within the range of medium probability which is between 0.21 and 0.30. This means that the probability of selecting an optimal variant for energy technology is the same for the all considered options (0.233 vs. 0260 vs.0.256 respectively). Concerning the separate sustainability dimensions (economic, environmental, social and technical), their similar values can be likely guided by the decision weight of the outcomes. Taking the environmental outcome, followed by the technical, into account, the values obtained for the CPT show that Variant III with 0.256 is the most optimal compared to Variant I and Variant II. These above-mentioned values were interpreted in the context of a typical person's attitude toward risk taking in terms of gains and losses (Table 9). With respect to the description of probability values (high, medium, and low) presented in Table 9, the CPT values of all three variants are within the range of low probability of risk (Probability 1 = 0.0–0.4). It is worth mentioning that this probability differs from the experts' assessment. It means that there is a low proclivity to risk when it comes to gains and risk aversion concerning losses. People reinforce their risk averse preference, which favors energy sustainability, and they prefer to take the chance of non-sustainable energy development rather than make some changes.

Table 9. Typical people's attitude toward risk of gains and losses in the light of Industry 4.0 for energy sustainability (from the PT perspective).

	Gain	Loss
High probability values (0.0–0.4) (3)	Risk preference: Risk aversion Underlying belief: Industry 4.0 is conducive to economic, environmental, social, and technical sustainability in the energy sector; it carries a high probability of benefit Industry 4.0 preference: prefer the certainty of benefit offered by sustainability Framing intervention: use gain frame messages to emphasize certain benefits of sustainability in energy. Reinforce risk averse preference.	Risk preference: Risk proclivity Underlying belief: Energy sector carries a high probability of non-sustainable development of energy industry. Industry 4.0 preference: prefers to take the chance of living in a non-sustainable environment of energy industry rather than accepting some needed changes or restrictions in using energy. Framing intervention: use loss frame messages to highlight the certainty of non-sustainable development of energy industry. Reframe the choice to be between the certainty of non-sustainable development of energy industry and the uncertainty of living in n energy a sustainable environment.
Medium probability values (0.5–0.7)	Risk preference: Medium risk proclivity Underlying belief: Industry 4.0 is conducive to economic, environmental, social, and technical sustainability in energy sector; it carries a medium probability of benefit. Industry 4.0 preference: prefers the certainty of benefit offered by sustainability. Framing intervention: use gain frame messages to emphasize certain benefits of sustainability in energy.	Risk preference: Medium risk aversion Underlying belief: Energy sector carries a medium probability of non-sustainable development of energy industry. Industry 4.0 preference: prefers to take a chance of living in a non-sustainable environment of energy industry rather than accepting some needed changes or restrictions in using energy Framing intervention: use loss frame messages to highlight the certainty of non-sustainable development of energy industry.
Low probability values (0.8–1.0)	Risk preference: Low risk proclivity Underlying belief: Energy sector carries a low probability of benefit Industry 4.0 preference: prefers to take the chance of non-sustainable energy development rather than to make some changes Framing intervention: use loss frame messages to emphasize the benefits of energy industry for sustainability by highlighting the economic, environmental, social and technical losses from non-sustainability. Low risk seeking favors sustainable energy industry development.	Risk preference: Risk aversion Underlying belief: it carries a low probability of non-sustainable development of energy industry Industry 4.0 preference: prefers the certainty of benefit offered by sustainability and undeterred by low probability of non-sustainability in energy Framing intervention: use gain frame messages to emphasize certain benefits of energy sustainability. Reinforce risk averse preference, which favors energy sustainability.

Table 9 illustrates the attitudes toward risk (perceived as uncertainty) based on the probability and framing of different outcomes, and provides a description of the probability's ranges presented in the paper. These are the main differences between other models and the methods concerning decision making processes as presented in Table 2. CPT can provide a framework for analyzing the impact/challenges of Industry 4.0 on entrepreneurship relationships. Kahneman's approach can provide implications to be taken into account when examining decision making in situations of risk in the realities of the fourth industrial revolution.

Whereas, for high probabilities, the function assumes values lower than the corresponding probabilities. This means that people are led to overstate low probabilities and under-record high probabilities (see details in Table 9).

6. Discussion

6.1. Interpretation of Results

Examining the CPT values, it is worth emphasizing that the Cumulative Prospect Theory value is opposed to the normative decision making process, and it is focused on a semi-subjective judgment which may lead to vagueness and uncertainty. This was caused by the two methods applied in the evaluation of energy technologies: (1) fuzzy AHP was used for assessing each energy technology to provide the dimensional outcomes needed to calculate CPT value. It was carried out because the various measurements units give more objectivity and reliability in evaluation than in the case of other multicriteria methods; (2) for calculating the CPT values, probabilities corresponding to the above-mentioned outcomes were assigned based on their subjective opinions. The results achieved have delivered very similar CPT values for each technology options (0.233 vs. 0260 vs. 0.256 respectively). The decision weights of each dimensional outcome across the all energy technology variants are the same values. Based on the analysis, these values are dependent on the fuzzy-based outcomes computed for assessing the technologies. Because the outcomes calculated based on fuzzy AHP coincide with each other, the decision weights of dimensional outcomes present the same values. According to CPT, the higher the value the better, which means that the variant is chosen as optimal. The probability used in CPT depends on the expert's judgment expressed here as outcomes. This has impact on the CPT values in the following way: if, for example, the probability for an economic pillar increases, it increases the CPT value; and if probabilities for any dimensions go up, CPT values increase.

Similar research was done by the authors in which they changed the parameters for probabilities to where environmental dimension is 24.8%, economical is 30.8%, social 8.4%, and technical one 36%. These probabilities were computed using analytical hierarchy process (AHP) based on the calculator available at https://bpmsg.com/ahp/ (accessed on 25 October 2021). Each dimension treated as outcome was given weights (probability values) based on the judgment of the same experts. The results have been presented in Table 10.

Table 10. Recalculation of the CPT values for the energy technology variants; decision weights were calculated using http://psych.fullerton.edu/mbirnbaum/calculators/cpt_calculator.htm (accessed on 25 October 2021).

Alternatives	**Variant 1**		**Variant 2**		**Variant 3**	
Sustainability Criteria (Dimensions)	**Outcome (Fuzzy AHP)**	**Decision Weight of Outcome**	**Outcome (Fuzzy AHP)**	**Decision Weight of Outcome**	**Outcome (Fuzzy AHP)**	**Decision Weight of Outcome**
Economic	0.06	0.221	0.1	0.221	0.12	0.221
Environmental	0.45	0.323	0.5	0.323	0.46	0.323
Social	0.05	0.266	0.05	0.266	0.05	0.266
Technical	0.35	0.301	0.36	0.301	0.38	0.301
CPT Values	0.273		0.260		0.256	

For the recalculation of the CPT using different probabilities for the sustainability dimensions, the obtained values depict Variant 1 as the most rationale in the decision making process in which environmental has gained the greater values. The outcome influences the decision weight of the outcome through probabilities. By manipulating the probabilities' parameters we can observe how the decision weight of the outcome may be changed, which then influences CPT values. Making decisions in accordance with the descriptive method of PT says that people choose lower values to avoid risk of loss. They are not as afraid of losing things they do not have as of losing things they have already possessed.

6.2. Methodology

According to the literature concerning PT [103], the authors of the paper have made an attempt to implement CPT in their considerations as to which prospect is a product of the decision weights and the value of the potential outcome. CPT achieved for Variant 1 of technology is 0.233, while for Variant 2 it is 0.260 and for Variant 3 it is 0.256. It seems appropriate to apply it to uncertainty as well as to risky prospects with any number of outcomes. It allows for differentiating weighting functions for gains and for losses. As shown in Table 9, it also confirms a pattern of risk attitudes: risk aversion for gains; risk aversion for losses; risk seeking for losses of high probability; risk seeking for gains and risk aversion for losses of low probability [103]. Further research could be done using opportunity/alternative costs theory, which covers the subject of making decisions and the choice between various alternatives.

The methodology used has taken into consideration the environmental aspects of sustainability, which affect energy generation and natural gas consumption more than social or economic aspects, compared to current use NGUS. For evaluation, considering the data from Table 7, the technical dimension is still of great importance, e.g., the reliability in the supply chain compared to the traditional dimensions of the triple bottom line. The evaluation of technology depends on the type of industry and the complexity of subject evaluated.

Since different types of sub-criteria are involved in evaluating energy technology for energy sustainability Industry 4.0, a comprehensive analysis and a selection of indicators by energy experts in energy reports is required to make a reliable assessment basis on which an appropriate decision can be made. On the other hand, although these technologies are comparable, additional expert knowledge about sustainability concept, and CHP technology could ensure the fairness of evaluation.

A combination of the fuzzy AHP and CPT with the assistance of other existing methods from the MDCA family (like fuzzy TOPSIS) can increase comprehensiveness of the methodology in providing sustainability assessment [100]. The methodology used in this paper outlines a predictive perspective aligned with company incentives. The results of the research reveal that the use of fuzzy AHP is so far mainly academic whereas PT can be considered a deliberative approach for solving difficult energy decisions that stand in the way of sustainable, energy efficient and reliable manufacturing. Through the connection of infrastructure to the digital workforce and with the prospect of theory-based decision making, facilities will be able to implement any kind of technology to take advantage of the potential of energy choices under sustainability indicators.

6.3. Implications for Scholars

The optimal decision obtained based on criteria CPT valuation might have different values from those obtained when an optimal decision is made using Expected Monetary Value (EMV), which is based on the objective criterion of maximizing the expected monetary value. CPT constitutes the opposite alternative to the EMV, because CPT places a lot of weight on possible losses (due to the loss aversion parameter). In other words, even the possibility of a very high income cannot compensate for the fear of losing. The suggested approach applies objective valuations of relative outcomes based on experts' judgment and their subjective probabilities (all sustainability dimensions have the same likelihood values). It in turn enables one to examine complex decision problems according to the decision maker's attitude toward risk (based on value function), losses (loss aversion parameter) and probabilities.

The literature overview revealed the fact that more attention has been focused on opportunities of Industry 4.0 application [3], showing positive relationships for environmental sustainability [129], and that study has been done about the possibility of using energy issues in the concept of sustainable Industry 4.0. This means that the current literature review provided evidence that research on integrating Industry 4.0 instruments in energy sustainability is still far from maturity.

The authors examined whether CPT allows for making decisions about energy efficient investment in Industry 4.0 and how it affects investment in energy efficient technology. Considering the obstacles to the implementation of energy efficiency technologies [130] (e.g., lack of knowledge about energy technologies, or low level of funding, risk of production), challenges exist for implementing Energy 4.0 concept combining Industry 4.0, sustainability, energy issues. Future implementation of Energy 4.0 considering the PT perspective could be fruitful for energy sustainability, and could be further verified by many manufacturing companies, regardless of their size, turnover and digital level as was performed in the study [129]. Therefore, it appears that there are many research and examination opportunities.

More emphasis has been placed on of how to employ PT and AHP in Industry 4.0 to choose the optimal variant or make the best decision. The researchers have tried to answer the following question: Can we make optimal decisions in conditions of uncertainty? In addition, how does one go in the Industry 4.0 direction at the same time? Industry 4.0 does not specify accurate assessment methods, but it makes analysis of the existing ones or it tries to combine them. Moreover, the discussion concerning how energy technologies may be transitional to Industry 4.0 seems to be simultaneously necessary and prospective of things to come.

6.4. Implications for Practitioners

This research enhances the knowledge and awareness concerning Industry 4.0 in the context of energy sustainability for energy sector. By joining the PT with multi-criteria methods (fuzzy AHP) the decision-making process is possible to be in the practice, providing continuous improvements of operations. The applied energy assessment approach can allow selecting optimal energy technologies considering at least three sustainability dimensions (economic, environmental and technical). It might help practitioners choose and implement 4.0 technologies contributing to energy sustainability. Thanks to this approach, practitioners can manage and streamlined their manufacturing processes. The achieved approach can serve as a guideline for "energy" entrepreneurships which may act sustainably by delivering improved quality products, reducing the use of natural resources using Industry4.0 technologies. In future, decision-makers of facilities should take a challenge to apply this approach to mainstream their energy policies.

Based on the results of the research, the main implication for practitioners is the dominant role of sustainability due to the adoption of energy solutions or technologies and associated I4.0 benefits. Another implication concerns the human resources. Because more and more knowledge and technical skills is required in the workforce so that the employees can deal with more advanced technologies.

6.5. Challenges of Industry 4.0

Because Industry 4.0 provides new features and possibilities, it creates challenges for energy sector or energy field in aspects of drives under the sustainability dimensions. The authors have collected the most notable challenges (see Table 11) that they have been found in the literature and based on their knowledge. These challenges representing energy sustainability outcomes were divided into the sustainability pillars (economic, environmental, social and technical).

Table 11. I4.0 challenges supporting the sustainability dimensions.

I4.0 Challenges	Energy Sustainability Outcome			
Drivers	**Economic**	**Environmental**	**Technical**	**Social**
Improve efficiency through energy technology in production	Input cost optimisation, productivity and efficiency	Use clean resources renewable energy	Application of efficient machines and technology [131]; Remote energy monitoring, diagnostic;	Energy tracking/Management; Knowledge sharing increased
I4.0 employees (Human and machine action)	Reduction of employee cost through the possibility to simulate modeled impact of process- steps on employees before thier recruitement	Reduction of the usage of natural resources and impact; Prevent production mistakes	Reduction of production mistakes and damages	Safety and security monitoring; new workforce technical skills, new knowledge-based roles for workers [132]; Better working conditions through ergonomically adapted workstations
Novel business model	New ways of value creation [133]; Reduction of cost through the possibility to design and test new models before setting up by virtualization;	Prevent in the usage of natural resources, renewables energy	Integration of business processes across the industrial plants, process-and service -oriented business models [134]	Better employee experience; Job opportuni-eties/worforce hired; Responsiveness to the market
More efficient digitalized production and quality products	Boosting efficiency, becoming more agile to respond to market unpredictability, improve quality; Economic stability;	Saved energy and less production waste; Efficient use of raw materials	Increased innovative capability throught introducing new (energy) technology	Higher quality products; Enhanced customization
Process/technology integration	Cost reduction in the intregation of technology and shop floor-equipment through across the entire energy value chain; Reduction of production time	Environmental protection	Dynamic configuartion processes [135]; Process automation and improved technology [136]; Integration through real-time energy data flow that are cloud-based	Human machine collaboration; Safety

7. Conclusions

This paper examined the possible application of PT with fuzzy AHP methods within Industry 4.0 to assist decision making about energy efficient investment in order to help practitioners choose and implement 4.0 technologies that will contribute to energy sustainability. Through this paper, the authors have attempted using a decision making approach to explain how decisions will result in investments in energy efficient technology in Industry 4.0. It has highlighted how CHP systems provide evidence on the achievement of sustainability performance in an industrial plant while ensuring data transparency. By streamlining the technology based on function support, decision-makers can make reliable decisions oriented toward energy sustainability. The weighting of technology sub-criteria was performed for the purpose of strengthening decisions in the use of PT.

Regarding the first research question (RQ1), only one energy technology was analyzed (cogeneration system) due to its flexibility in application. It depicts a roadmap or blueprint for decision making through the incorporation the PT within Industry 4.0 and for helping transform traditional energy-intense facilities into energy efficient ones to achieve energy sustainability.

With regards to the interaction between the energy technology and the I40 adoption, it allows for enhancing the quality of manufacturing processes and their organization to support the shifts from a traditional production to IT-intense facility, providing highly efficient manufacturing and meeting the sustainability dimensions simultaneously (recovering energy, a precise measurement of energy use etc.). Moreover, thanks to the I40 technology (energy technology equipped with additional sensors), the industrial plant can avoid excessive cost for additional staff to measure energy use (e.g., energy auditors) and the cost of delocalization to the developing countries where the workforce has low wages; but in the case of subsidiaries it is a reduction of cost and time of energy data collection.

Reviewing the second research question (RQ2), the authors conclude that it is does not matter which I4.0 technology is reviewed each technology requires a different energy decision separately. In this context, depending on the type of technology, there are associated parameters and indicators, so a review should be performed carefully. However, an assessment approach might be applied for each technology as accepted by scholars and practitioners. Rational decisions surrounding energy use is a multifaceted process.

The conclusion is that organizations need to consider the Industry 4.0 concept as a contribution to sustainability. The authors of this paper have shown that PT with a decision-dependent reference point can reveal decision-makers' way of thinking because PT predicts that organizations tend to be risk averse with respect to gains, or when things are going well, and relatively risk seeking with respect to losses, as when a leader is in the midst of a crisis.

The advantage of this approach is that it does not require much allotted time or costs to perform the assessment or the involvement of other resources (e.g., human) for data collecting. This methodology provides an approach that might be incorporated within an energy sustainable policy, as part of Industry 4.0 exploring synergies between economic, social and environmental objectives and technical objectives. Moreover, it may be able to highlight the explicit implications of choices for decision-makers.

It does not matter how the results of the evaluation were achieved or how advanced the operational processes are within Industry 4.0, energy sustainability performance can be further refined and improved using more-advanced technologies such as digital metrics and artificial intelligence to provide a competitive advantage in the market.

The authors of this paper are conscious of the limitations of the research as well of the fact that the research methods used in the paper may be perceived as subjective because they are based on the experts' assessment and are characterized by individual approaches. This can be seen as its main disadvantage and objection. Nevertheless, the ability to combine PT with multi-criteria methods and to engage in the energy sector may be treated as the main advantages and potential areas for future research. The authors have also described an untypical concept of a decision-making process to be applied in Industry 4.0, which is a kind of novelty in the literature on the subject.

This paper also demonstrates the importance of making decisions in conditions of uncertainty and risk in order to achieve sustainable energy in the light of Industry 4.0. Thanks to Industry 4.0 and the possibility of using it for energy efficiency a novel term "Energy 4.0" was born.

Further research would be designed to answer the following questions: To what extent does this affects optimal energy policy for sustainable Industry 4.0? What is the implication for energy policy of using multi-criteria decision approaches? Although the first attempt at using a complex methodology combining LCA-based methods, PESTEL and AHP has been carried out in the context of mainstream energy for the decision making process based on a real case of photovoltaics, the research examined [137] shows that more attention is required to search for methods of selecting the right technology options. Finding an answer to the above mentioned questions will be helpful in confirming the study documenting the application of MCDA in energy policy decisions by finding their interconnections [89]. Other research could focus on the criteria based on EMV analysis and the achieved results could be compared with these from PT.

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