

Article

Economic Efficiency of the Internet of Things Solution in the Energy Industry: A Very High Voltage Frosting Case Study

Milos Maryska ^{1,*}, Petr Doucek ², Pavel Sladek ¹ and Lea Nedomova ²

¹ Department of Information Technologies, University of Economics, 130 67 Prague, Czech Republic; pavel.sladek@vse.cz

² Department of System Analysis, University of Economics, 130 67 Prague, Czech Republic; doucek@vse.cz (P.D.); nedomova@vse.cz (L.N.)

* Correspondence: milos.maryska@vse.cz; Tel.: +420-604-228-819

Received: 22 December 2018; Accepted: 5 February 2019; Published: 13 February 2019



Abstract: This article deals with the deployment of an Internet of Things (IoT) technology within the energy industry (energy distribution) in the Czech Republic. The first part of the article is devoted to an assessment of the perspectives for developing IoT applications and implementing them within the economy, and then examines how the principles of multi-criteria decision-making are used to select IoT technologies for deployment in the energy industry. The selection of technology is also followed by the selection of the specific application with the highest potential benefit for the company using such a method to select the technology. The selection solution is demonstrated and further discussed from the technological and financial standpoints and illustrated via the example of choosing among two alternatives for a real-world application, very high voltage (VHV) frosting (in electric power transmission engineering, which is usually considered as any voltage between 52,000 and 300,000 V). The application solution is analyzed by how it relates to the direct vs indirect measurement of glaze ice. The result of this technical and financial analysis was that the direct glaze ice measurement variant is clearly the more advantageous one. The direct-measurement variant has a three-year payoff period, compared to six years for indirect measurement. Further, the benefits from the direct-measurement variant are 2.25 times larger than the other variant, and the five-year net profit value amounts to a profit for the direct-measurement variant while it results in a financial loss for the indirect-measurement variant. The recommended variant is to measure the icing of VHV lines directly.

Keywords: Internet of Things; economic efficiency; energy industry; internet services; information technology; information technology services; electric utilities; electricity sector; energy

1. Introduction

The Internet of Things is a newly arising and very dynamically developing information technology. It is expected to provide new and very special applications and services that will interweave practically all areas of human activity, from industry through logistics, sales, and entertainment including our leisure-time activities. It can be expected that in the near future, the IoT will not only impact all of these areas, but also become an inseparable, key part of them.

The term “IoT” is nothing new; on the contrary, it is a fairly old one, with the first mention of it dating back to 1980, even though at that time it did not bear its current name, the Internet of Things. The Internet of Things, as a concept, was not officially named until 1999. One of the first examples of an Internet of Things is from the early 1980s, and was a Coca Cola machine located at the Carnegie

Mellon University. Local programmers would connect by Internet to the refrigerated appliance, and check to see if there was a drink available, and if it was cold before making the trip [1–3].

The term Internet of Things as understood today, was first used by Kevin Ashton in [4], in connection with radio-frequency identification (RFID) technologies.

In the period leading up to 2013, the IoT concept developed into a system that joins very different technologies with differing functions, by utilizing a variety of communication protocols. Examples include sensors, GPS devices, mobile devices, vehicle tracking, remote car-motor switching, etc. In the last two years, there has been general acceptance for a definition of the IoT as a global network infrastructure with self-configuration capabilities that is based on standard, interoperable communication protocols. The protocols are based on two characteristics: within them, physical and virtual “things” are identified by physical attributes, and virtual individuals utilize an intelligent interface and are integrated into a broad information network [5–7]. Specifically, the integration of sensors/actors, RFID chips, and other communication technologies serve as the foundation of the IoT and explain how various devices around us can be connected to the internet-Figure 1. They also enable these objects and devices to cooperate and mutually communicate to achieve shared goals [8].

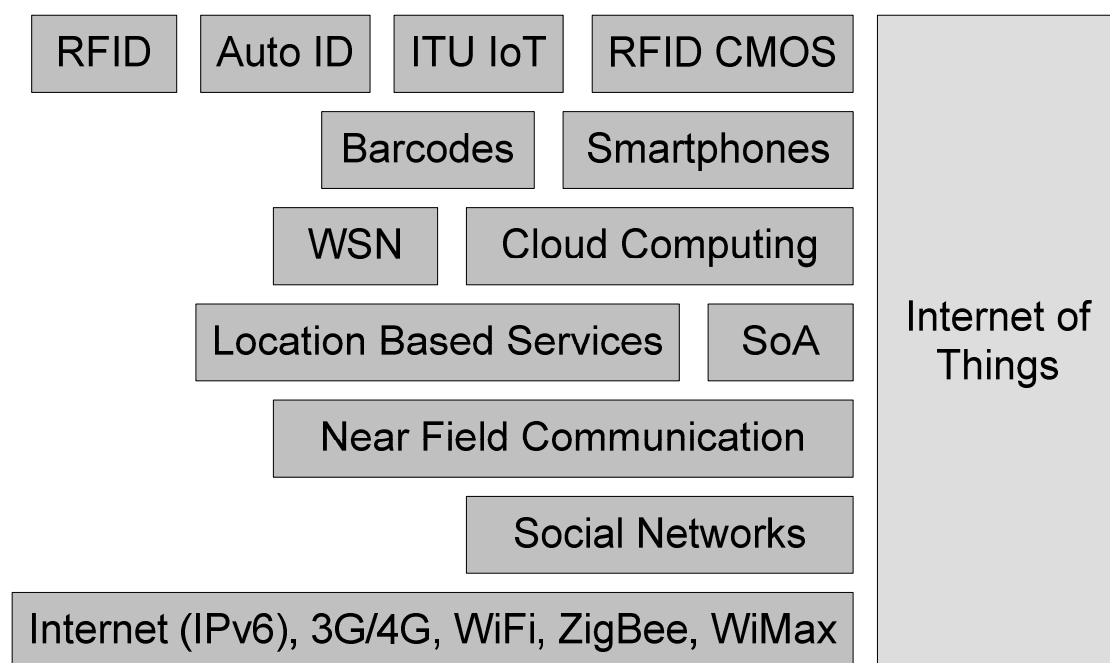


Figure 1. Technologies connected with the IoT concept [9].

For now, the IoT is developing most in industry in the form of the Industrial Internet of Things (IIoT), where intelligent sensors have become an integral part of manufacturing and assembly lines (monitoring). The IoT has also become fairly widespread within logistics and certain services, including health services. Thanks to developments in wireless communication technologies, smartphones, and sensor networks, more and more “Things,” i.e., intelligent objects, are being connected to the IoT. As a result, the IoT (or for manufacturers, the IIoT) is significantly influencing new concepts and architectures in enterprise information systems (EIS) [10]. The impact of IoT technologies on EIS is shown in Figure 2 [11].

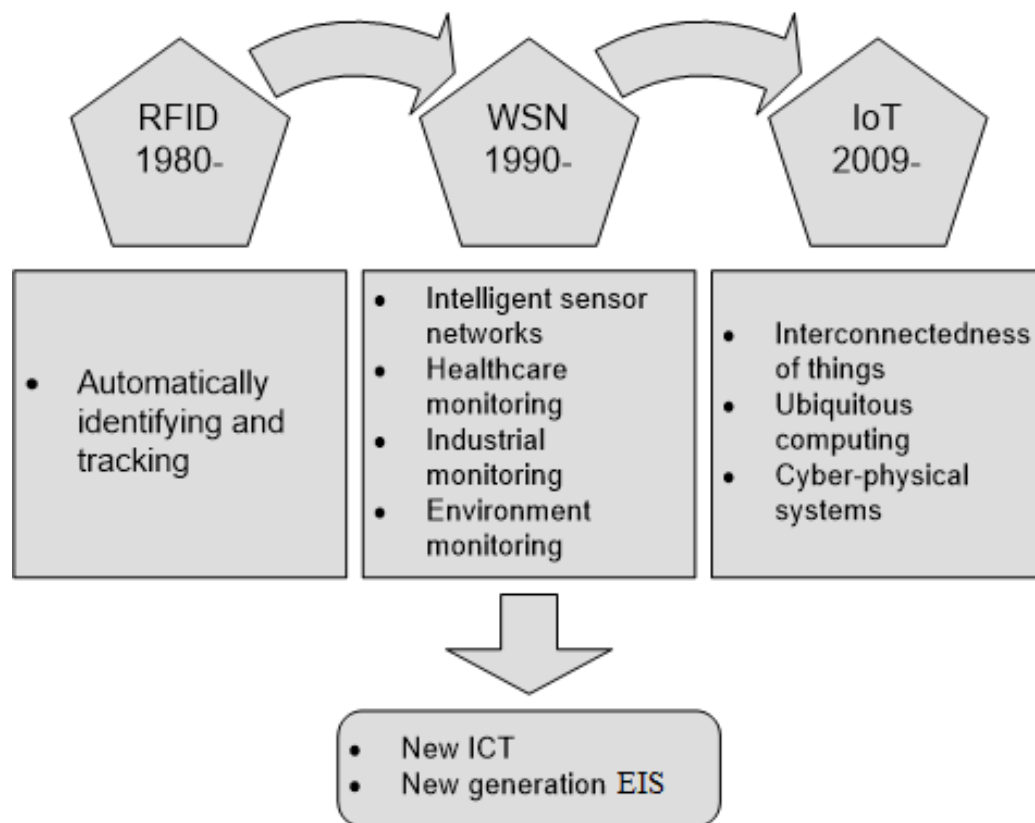


Figure 2. Technologies connected with the IoT and their effects on EIS [12].

At present, the IoT is seeing research and development in practically all major research centers and companies. Within the European Union, the European Research Cluster on the Internet of Things (IERC) has proposed a number of IoT projects and created an international IoT forum [13] to develop a joint strategy and technical vision for the use of the Internet of Things in Europe [14,15].

In general, we can state, that IoT is old technology, which has become increasingly important and usable in the last few years thanks to increasing IT/IoT knowledge and the decreasing price of IT/IoT devices. The IoT is spreading almost everywhere, we can find it in households, industry, transportation, medicine, etc. Important factors, which are speeding up the usability of IoT include the pressure and financial support of the European Union to create intelligent cities, intelligent transportation, etc.

Another major player in the world IoT market is China [16], which has developed a broad strategy for the utilization of IoT applications in its economy and plans to invest 166 billion dollars into IoT projects, including IIoT projects (their IoT investment up until 2015 was 80 billion dollars) [17]. China's goal is to become the leader in setting international norms for IoT technologies [18]. This is also supported by the fact that according to the China Academy of Information and Communications Technology, 30.3% of China's GDP came from the digital economy, and the growth of this share relative to 2015 was an unbelievable 18.9 percentage points [19]. This growth can also be traced to the activities of individual firms: China Mobile, for example, plans to invest over 300 million dollars in the IoT [20]. The Chinese market for IoT technologies has a faster yearly growth than its GDP, and the expected values for yearly IoT growth amount to 20%–30% until 2020.

A new approach to integration of the social networking concept into the Internet of Things has emerged and is gaining popularity and attention in research circles due to its vast and flexible nature. It has the potential to provide a platform for innovative applications and network services in an efficient and effective manner. This level of integration and next phase of IoT is called the Social Internet of Things [9,21].

2. Problem Formulation

Technicians' and researchers' growing interest in the Internet of Things is also reflected in the business sphere. This concept and the technologies surrounding it amount to a revolution in our understanding of the role of information technologies in the lives of people and companies. The overall transformation of the IoT is naturally generating many investment opportunities in a variety of areas of the economy. Despite all these potential opportunities that come with the IoT, the existing literature, including scientific articles, largely overlook one of the key areas of the economy, namely, the application of IoT for VHV in the energy industry.

We identified several articles that discuss IoT topics in the energy industry [22–24], nevertheless, they discuss and analyze different issues and they mention issues that are solved in this article.

This article aims to identify investment opportunities within the application of the Internet of Things to the energy industry in the Czech Republic. Besides discussing a procedure for assessing investment variants, this article includes a case study on investment opportunities in the energy industry under Czech conditions for the area of distribution, including a financial assessment of individual variants.

3. Methodology

The basic data obtained for this article primarily comes from an extensive survey among experts in the Czech energy industry. This survey was conducted among fifty experts from a variety of businesses as well as the academic sphere in the 2016/2017 winter season. To obtain the relevant data, a total of 77 workshops were held; these took place in two rounds, see Figure 3 (Area 1). Alongside the workshops, selection and comparison of available IoT technologies (Figure 3, Area 2) on the Czech market was also performed. The selected technologies were then utilized during the formulation of the case studies.

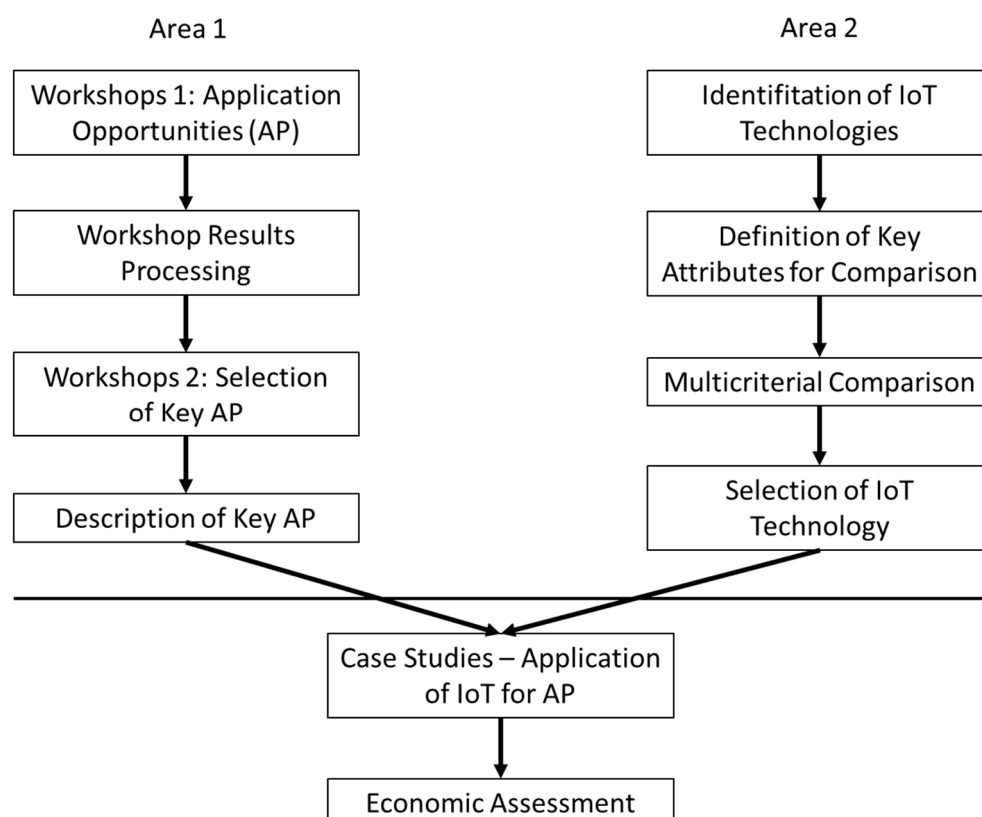


Figure 3. Research scheme.

3.1. Area 1—Workshops

In the first round of workshops (Figure 3 Workshops 1), 50 workshops with experts from a variety of businesses and the academic sphere were organized. The workshops had a structured form, with questionnaire support. Our questionnaires and identifying technologies for IoT and business opportunities were based on the technique of guided questioning, with the use of open and closed questions [25].

Besides defining and providing a basic description for identified application opportunities, one important part of these workshops was assigning application opportunities to one or more streams that can, based on the subject literature and in the authors' opinion, be identified for companies that focus on the production and distribution of electrical energy as follows:

- Business—this is focused on sales of electrical energy generated in other streams; this is the only stream that directly communicates with the end customer, no matter whether this is in the form of a physical or legal entity [26].
- Facility—according to [27], this is a comprehensive set of support services for the administration of buildings and real-estate property.
- Mining—this is focused on all areas connected with extracting mineral raw materials, such as mining coal and extracting oil, gas, etc. [28].
- Production—this is focused on all areas and methods of electrical energy production, both from renewable sources (the water, wind, and sun) and from fossil sources, etc. [26].
- Distribution—according to [29] its goal is to fully function as an effective administrator for the assets of the distribution system in the power-supply area of electrical energy distribution; in the Czech Republic, it must comply with the conditions of the Energy Act and the rules of the Energy Regulation Office.

Another important piece of information acquired during the first round of workshops was a definition of the priorities for the execution of identified application opportunities. The research distinguished three priority levels, with level 1 being the most important and level 3 being the least important. For some application opportunities, no priority was set, and for this reason, they are marked “priority N/A.” The priorities were based on a subjective evaluation of the significance of each application opportunity by each workshop member. The priorities take into account such factors as societal benefit, investment costs, implementation speed, likelihood of success, etc.

The outputs of all 50 workshops were processed, and then the data from the individual questionnaires that were completed at the workshops was evaluated. This enabled us to merge duplicate identified application opportunities and create a set of unique application opportunities.

In the second round of 17 workshops (Figure 3 Workshops 2), the 124 unique application opportunities identified in the first round were assessed by experts and academics. The basic difference between the first and second round of workshops lies in the fact that in the first round of workshops, each expert and academic was questioned separately to keep them from influencing each other. In the second round, we performed group workshops (while always taking into account specific experts' and academics' abilities). Another difference was the form of workshop; in the second round of workshops, no questionnaires were used; the experts and academics defined the importance (priority) of individual application opportunities and their usability in practice, based on their personal feelings. Also, in the second round, the survey participants assessed the difficulty and benefit of each given application opportunity.

In the last step of Area 1 (description of key application opportunities (AP)), a detailed description of selected AP for which some priority had been assigned was prepared, that is, opportunities that had no priority assigned (the N/A value) were excluded. Every application opportunity was described by way of the key factors affecting its implementation and operation. A description of each opportunity was produced in a structured form, with cooperation from the expert or academic who proposed the given application opportunity. In situations where a selected application opportunity was identified by

multiple survey participants, its description was always provided by a single survey participant. This participant was selected randomly. The individual opportunities are strongly dependent on various factors such as the available technologies, the state of the market in the area of energy, etc. Because of this, the list of identified opportunities can vary based both on the composition of the workshop and on developments in IoT-related information technologies. We converted the values obtained when evaluating application opportunities into two numeric values and then plotted them on a graph for each stream, where benefits (financial, legislative compliance, safety, reliability) were plotted on the X axis and difficulty (of implementation or of operation, as well as costs, execution, etc.) was plotted on the Y axis. During the decision-making, this graph served to define the applications' benefits as well as the difficulty of their implementation (Figure 4).

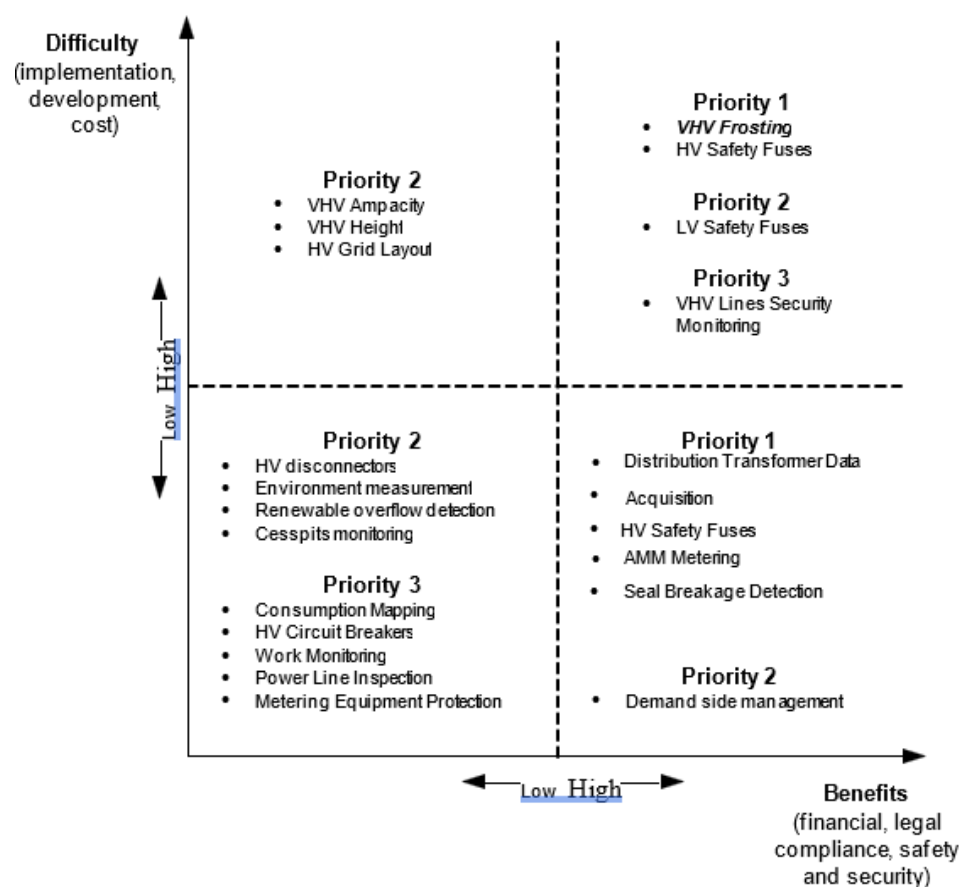


Figure 4. Evaluation of IoT applications' potential in the distribution stream. Source: authors. Legend for Figure 4: VHV = Very High Voltage, HV = High Voltage, LV = Low Voltage, AMM = Metering = Intelligent Metering by way of Sensors.

3.2. Area 2—IoT Technology Selection

Activities within Area 2 (Figure 3) were also divided into four steps, which were taken in parallel with the organization and execution of the individual workshops. In the first step, the IoT technologies available in the current Czech market were identified, without regard to their application method in the real energy-industry environment. IoT technologies that are potentially suitable for the energy industry were identified based on an analysis of extensive information from the individual technologies' creators, as well as on research into available information within the information sources offered by science libraries. Each of these areas was described within the research so that there would be a clear definition of which energy-industry area it covered and so that the areas would not overlap. Overall, we identified 12 potential IoT Technologies (for example NB-IoT LTE, SIGFOX, LoRa, Telensa,

Weightless). In the second step, we composed a set of 23 attributes that could be used to characterize the selected IoT technologies. We then also chose seven fundamental attributes from among these. Specifically, these were:

- The Service Level Agreement (SLA) for guaranteeing message delivery.
- The modem's energy demands and battery life; a long life means a longer service cycle on communicating devices.
- Range in kilometers in environments with various settlement types (rural / urban agglomeration); a higher range means better coverage.
- Downlink capacity; a higher transfer capacity enables the sending of, e.g., images or videos.
- Latency during normal operation.
- Device jammability; easier jamming prevents use in situations where communication needs to be guaranteed.
- Number of end-devices per base station; a fairly high number of devices per base station is a must for high local network capacity, as it enables the use of a large number of sensors in one locality.

In the third step, we performed a comparison of the individual IoT technologies using multi-criteria evaluation methods; this comparison was based primarily on the seven basic attributes that we had defined in the preceding step. The following four methods were used for multi-criteria evaluations: weighted average, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Elimination and Choice Expressing Reality I (ELECTRE I), and Elimination and Choice Expressing Reality III (ELECTRE III), which are described in detail in [30,31]. For the purposes of this article, we will only state that the final selection of an appropriate technology was performed using the ELECTRE I method, which is based on dividing the variants into two indifference groups: a group containing efficient variants and a group containing inefficient variants. The ELECTRE I method defines several important prerequisites that must be met before it can be used. These prerequisites are: knowledge of the criteria matrix, normalized criteria weights, and preference and dispreference thresholds. To identify an advantageous variant, one must create a matrix of preferences and dispreferences that contains sets of criteria that are preferred or dispreferred among the individual variants.

The last step, selection of IoT technology, covers the final selection of the most advantageous variant. The most advantageous variant was selected based upon multi-criteria assessments of the individual IoT technologies and these assessment results. For each of the technologies, we obtained an ordering, and based on this ordering, we selected the most advantageous IoT technology variant.

For a detailed description of the individual technologies and how they were selected, see the articles [30,32].

3.3. Case Studies and Economic Assessment

In the last two steps (as per Figure 3), the final selection of the application opportunity was performed. The shortlist contained variants where strong benefits and low implementation difficulty could be expected, or where there were strong benefits along with a justifiably high implementation difficulty. These considerations must always be combined with higher priorities. During selection, one must also take into account other factors that cannot be expressed in the graphical description in Figure 4. These include societal impact, energy-supply security for the target financial entity, etc.

For the application opportunities selected based on the above criteria, detailed business cases were created. These identified the main drivers affecting the opportunities' financial efficiency. The key financial indicators that were factored into our analysis included: one-time benefits, annual recurring benefits, one-time acquisition costs, annual recurring costs, 5-year TCO (total cost of ownership), 10-year TCO, 15-year TCO, 5-year NPV (net present value), and simple payback period in years.

The detailed processing of the selected variants into the form of business cases with the above-stated criteria was absolutely key. Based on this comprehensive assessment, we could perform the first comparison of selected variants and move on to simple exclusion of inefficient variants. In this

context, inefficiency means the situation where a variant does not bring a positive (or in some cases, an expected) financial result within a defined period.

In the framework of this article, we identified the “Wind and Glaze-Ice Detection” application opportunity for pilot verification of the proposed solution.

4. Results and Discussion

4.1. Selection of Variants for the Case Study

Within the 67 workshops, we identified 124 IoT application opportunities that can be applied within the energy industry. In the first phase, we used the workshop outputs to assign the application opportunities to streams by priorities, see Table 1.

Table 1. Numbers of identified opportunities by streams and priorities.

Stream	Priority 1	Priority 2	Priority 3	Priority N/A	Total Identified
Business	4	0	1	30	35
Facility	2	6	9	3	20
Mining,	1	2	3	4	10
Production,	2	3	6	4	15
Distribution	7	9	6	22	44
Total	16	20	25	63	124

Out of the 124 application opportunities identified, 61 (roughly 49%) with priorities from 1 to 3 were selected for further processing. These 61 application opportunities were evaluated in terms of their implementation and development difficulty, expense, and financial, safety, and legislative benefits. The evaluation output is shown for the distribution stream in Figure 4 below, which is based on a standard Ansoff’s strategic opportunity matrix [33].

The key variants for putting applications to practical use are those that are located in the right-hand quadrants, i.e., those where there is an expectation of strong benefits and simultaneously, a relatively low implementation difficulty (the bottom right quadrant). The top right quadrant, meanwhile, is another option for acceptable variants, when the benefits are strong and the implementation difficulty (or expense) is justifiable. These criteria were also combined with that of priority, and thus only applications with a priority of one were selected.

Out of the priority-one applications in the right quadrants (shown in Figure 4), the application opportunity “Glaze Ice on Very High Voltage Wires” was chosen for the preparation of a detailed case study. Very high voltage refers to the voltage between two conductors of a system, or between any conductor and the ground, and in electric power transmission engineering, very high voltage is usually considered any voltage between 52,000 and 300,000 V.

This application opportunity was selected based on a detailed discussion with company management and initial assessment of this and other Priority 1 application opportunities. The key justification for the selection of this variant was its positive societal impact, time needed for implementation, side effects of the implementation (new data useable for another analysis) combined with its impact on the company’s finances (cost reduction). Regarding the societal impact, we primarily have in mind the situation where large electrical outages occur that must normally be made up for in costly and risky ways, e.g., by redirecting electrical energy over a different distribution network, thus overburdening it, or through purchases from abroad, etc. Less inconvenience for citizens in connection with the above situations is another factor. None of the other identified variants in the right quadrants (Figure 4) have such a broad societal impact.

Business Case: Wind and Glaze-ice Detection

Electrical energy supplies are critically dependent on the physical state of the distribution system. Thus, in the winter, glaze ice is a key factor influencing the status and functionality of the system,

and it must be detected in time. Wind conditions, which affect infrastructure directly and can also themselves contribute to icing, are another key factor.

Strong financial benefits connected with less frequent electrical energy supply outages for end users and timely detection of such outages are thus expected from the “VHV Frosting” application opportunity. Besides the cost reduction, an improvement in the distribution company’s image in the eyes of customers is also expected from this variant.

Business Case Environment in the Distribution Stream

The basic characteristics of the distribution stream at the selected company are listed in Table 2.

Table 2. Distribution stream characteristics at the selected company.

Characteristic		Unit (Thousands)	Number of Units
Region Supplied		km ²	52
Number of Consumption Points		Number	3650
divided among	large purchasers–VHV and HV	Number	15
	small purchasers–businesses–LV	Number	436
	small purchasers–residences–LV	Number	3200
Maximum Network Load		MW	6
Wire length		km	164
divided among	VHV	km	10
	HV	km	51
	LV	km	104
Number of Transformer Stations		number	59
divided among	Own Stations	Number	46
	Others’ Stations	Number	13

Note that the company has roughly 300 substations available.

4.2. Business Case: Wind and Glaze-Ice Detection

The business-case description can be broken up into these parts:

- The problem being solved: the business case.
- The IoT’s impact on the problem and its proposed solution.
- The effects of applying the IoT to the problem.
- The options for a technical solution.
- The financial calculation.

4.2.1. The Problem Being Solved: The Business Case

The foundation and goal of the Wind and Glaze-Ice Detection application opportunity is proactive detection of glaze ice and wind, as these lead to problems that often cause very high voltage (VHV) and high voltage (HV) transmission wires to snap. Glaze ice, typically in combination with wind, causes trees to fall on wires or places a burden (the ice’s weight) on the wires, which then snap. Widespread problems of this kind do not occur often, but they have significant consequences for end-customers in that they demand crisis-situation resolution (e.g., from companies with high electrical energy demands), and the electrical energy distributor in that they require the distributor to find replacement routes for directing electrical energy, to make purchases from other companies, etc., which leads to additional costs for the electrical energy provider. Additionally, handling the excess energy that loses its outlet when supplies are interrupted is a problem all its own.

4.2.2. The IoT’s Impact on the Problem and Its Proposed Solution

IoT technology is important in addressing the problem identified here because it enables a proactive approach towards potential problematic situations. For electrical energy distribution networks, it serves as a preventive solution for losses caused by glaze ice, and for potential losses caused by other faults.

The solution is to deploy IoT applications that can detect glaze ice on HV and VHV lines (and possibly also selected sections of low voltage lines) in known glaze-ice regions.

The application of the IoT to the issue of glaze ice would work proactively to detect potential problems. Whenever a problem (glaze ice or wind that met the defined criteria) is detected, a crew could be sent out to remove the glaze ice. Alternatively, the voltage on the VHV line could be increased (thus heating it), in any places where that would be possible. Both of these approaches would enable the distributor to proactively prevent the fault and damage to the energy-distribution system, and shorten the electricity outage. In terms of solutions, two basic variants for detecting glaze ice on lines are possible.

The V1 Variant is based on indirect detection via the measuring of humidity, temperatures, and wind speed (using measuring stations located on electricity poles) and the subsequent processing of the data obtained this way using a neural network (a classifier) trained on prior experience (meteo data from the Czech Hydrometeorological Institute and glaze ice announcements in the dispatching system).

The V2 Variant is based on direct measurement (using tensometers) of the dynamic load on a roughly 1m long “test wire” or on a metal stick placed in a special frame on a pole.

Both variants are thus based on the use of weather stations that are equipped with a glaze ice detector (or an algorithm for glaze-ice detection). In order to work optimally, these sensors must be present in all of the nation’s critical glaze-ice regions. Relative to the distribution system’s overall line length, roughly 0.8% of the Czech Republic’s VHV and HV lines are in regions of this kind.

Both of the variants indicate any critical states based on the data that they collect. The control system then expresses the collected sensor data in a way that enables the dispatcher to optimally predict potential problems and manage the network, send technicians out to the problem site, and so on. In terms of precision, the V2 variant, i.e., devices with direct glaze ice measurement, is the recommended variant; it is fundamentally more precise and provides better information than variant 1, which is strongly dependent on wind currents and other factors.

4.2.3. The Effects of Applying the IoT to the Problem

In terms of benefits, these are primarily:

- less frequent energy outages (reduction in case of glaze ice/snow of 75%, windstorm of 15%, etc.)
- reduced costs for servicing trips (the ability to focus strictly on directly threatened localities), especially for wire-repair trips that are never needed because the wire split has been successfully prevented. Total reduction of cost for servicing trips was over 30%.

In relation to the issue of undeliverable energy, the societal impact of shortening energy-supply outages can amount to tens of millions of Euros per year. However, this impact is not included among the direct impacts for the business case explored here.

Measuring Stations for the V1 Variant—Indirect Glaze-Ice Detection

To detect glaze-ice situations reliably, these measuring stations must be located in defined areas that are roughly 500 m apart, i.e., at roughly every other VHV pole and every fifth HV pole, thus, roughly two measuring stations per km of wire in glaze-ice regions, and one station per km at minimum. One prerequisite for the use of measuring stations is that they must be able to run without external energy (i.e., using a solar panel and a battery). Since two-way communication is not needed, and frequent data transmission is only needed after changes to basic weather parameters, it is enough for the devices to communicate wirelessly over a low-energy and low-capacity IoT network.

The meteorological factors that should be considered for measurement and transmission are: temperature, wind speed and direction, sunlight intensity, atmospheric pressure, and relative humidity.

If a professional weather station with sensors that capture all of the needed data is used, such a station can be connected to an IoT network modem locally using a serial interface such as RS232 or RS485, and the current values, or if appropriate max/min values, can be read one per a given interval.

Measuring Stations for the V2 Variant—Direct Measurement

The second measurement method, although it still includes the measurement of standard temperature, humidity, and wind force/direction factors, is based primarily on the direct measurement of ice magnitude by using tensometers to measure the force acting in the place where a 1–2 m wire or metal rod has been positioned. Each such wire or rod is placed in a construction that is fastened to an electricity pole. The advantage of this method is that the values it provides are directly those for the dynamic load acting upon a “simulated” wire. These values can then be converted into the force acting upon a real wire (N/m or kg/m), and this enables the distributor to obtain sufficiently precise information on the amount of ice at a given location. The information from the stations is transmitted to a processing database. Because the algorithm needed is fairly simple (in fact, it is simply the conversion of the force acting upon the suspension for the “wire simulator” into an amount of ice on the wire), the glaze-ice data can be calculated in the IoT application directly, before the information is transmitted to the dispatching system.

4.3. The Financial Calculation

Table 3 contains a financial comparison of the above two glaze-ice detection variants. Because the business-case data is sensitive, we present the calculations not as raw values, but as relationships, where the V1 variant is used as a base unit against which the V2 variant is compared.

Table 3. Comparison of the glaze-ice detection variants.

Category	Variant:	V1	V2
	Description:	Variant Using a Weather Station with a Glaze-Ice Detection Algorithm and without a Glaze-Ice Sensor	Variant Using a Weather Station with Direct Glaze-Ice Detection (a Sensor)
Benefits	One-time Benefits (thous. CZK)	0	0
	Annual Recurring Benefits (thous. CZK)	100%	225%
Costs	One-time Costs (thous. CZK)	100%	110%
	Annual Recurring Costs (thous. CZK)	100%	171%
Total Cost of Ownership	Total Cost of Ownership 5 years	100%	114%
	Total Cost of Ownership 10 years	100%	117%
	Total Cost of Ownership 15 years	100%	120%
Overall Balance of Benefits	5-year Net Profit Value V	Loss	Profit
	Simple Payback Period (in years)	6	3

A detailed analysis and discussion of the financial indicators is provided below.

4.3.1. Benefits

The overall benefits can be calculated as percentages of line losses related to relevant weather events (glaze ice or windstorms) that the solution prevents.

According to the distribution company’s findings, these losses can be estimated from the overall damage using the following breakdown:

- prevention of faults caused by glaze ice/snow: savings of 75% of the overall damage
- prevention of faults caused by fallen trees: savings of 20% of the overall damage
- prevention of damage caused by severe windstorms (rows of poles falling): savings of 15% of the overall damage.

Annual recurring benefits for:

- The V1 variant (indirect measurement) are 100%.
- The V2 variant (direct measurement) are 225%.

These benefits must be compared with the project costs stated below.

4.3.2. Costs

One-Time Costs:

3908 HV support points and 46 VHV support points exist within known glaze-ice regions. If we assume that the weather stations need to be set up at every tenth HV support point and every fourth VHV support point, roughly 400 weather stations are needed. The costs are calculated in the Czech Crowns (CZK)

The cost of the weather stations is:

- x CZK (100%) for the V1 variant,
- roughly $1.167x$ (116.7%) for the V2 variant, i.e., a price that is roughly 16.7% higher.

The weather-station costs must also factor in:

- y CZK as the costs for assembly, development, and testing,
- z CZK as the cost for creating the evaluation system.

These costs are identical for both variants.

Overall one-off costs for the weather-station project:

- we estimate the V1 variant's cost in CZK as: $400 * (x + y) + z = 100\%$,
- we estimate the V2 variant's cost in CZK as: $400 * (1.167x + y) + z = 110\%$.

Annual Recurring (Operating) Costs

The annual recurring (operating) costs will be similar for both variants, and they can be calculated as:

- the sum of the price for IoT communication when the number of devices (400) is multiplied by the yearly per-device price for providing communication (price), i.e. the two prices for IoT Communication = $400 * \text{price_V1}$ or $400 * \text{price_V2}$,
- plus, the cost of servicing inspections of IoT devices along with battery replacements, which are to be performed once per 5 years. Since the expected sensor life expectancy is 15 years, this cost is thus $3 * 400 * \text{bp}$, where bp is the battery price.

Thus, during the solution's 15-year lifetime, we estimate the overall operating costs for each variant to be the sum of the IoT communication costs and the servicing costs, i.e.:

- V1 variant: $15 * 400 * \text{price_V1} + 3 * 400 * \text{bp} = 100\%$,
- V2 variant: $15 * 400 * \text{price_V2} + 3 * 400 * \text{bp} = 171\%$.

Total Cost of Ownership

The TCO for each of the variants, i.e. the sum of the one-off costs and operating costs for their fifteen-year lifetimes are (a detailed description based on individual TCOs is given in Table 3):

- The V1 variant (indirect measurement): CZK: $400 * (x + y) + z + 15 * 400 * \text{price} + 3 * 400 * \text{bp} = 100\%$,
- The V2 variant (direct measurement): CZK: $400 * (1.167x + y) + z + 15 * 400 * \text{price} + 3 * 400 * \text{bp} = 120\%$.

One basic assumption of the above calculation is that the prices for the technologies under consideration and for other cost inputs will remain constant throughout the observed period. It follows from this that the V2 variant, the one with direct glaze-ice measurement is more financially advantageous despite larger one-off initial costs and operating costs.

5. Discussion and Conclusions

The process for selecting the most advantageous IoT technologies to support everyday operating processes is a very complex activity. Both the technological and financial aspects must be taken into account. Within this article, the financial aspect is covered in terms of both profit and cost.

This article focuses primarily on the financial aspect, and on comparing two application-opportunity variants for monitoring glaze ice in the energy-distribution system. The first of these variants (V1) is indirect glaze-ice measurement based on an estimate using secondary parameters such as wind speed, humidity, and more. The second variant (V2) for the VHV Frosting application opportunity was glaze-ice measurement based on direct measurement, i.e., on a single-purpose device, a tensometer installed solely to measure glaze ice on VHV poles.

Based on the financial evaluation, we can state that the V1 variant has a simple payback period of 6 years, while the V2 variant, direct measurement, has a simple payback period of only 3 years, despite having higher one-off costs and operating costs.

In light of this, it can also be seen from Table 3 that the net profit value in the 5-year calculation for the V1 variant amounts to a temporary loss, while for the V2 variant, this value is already positive after just 5 years.

The 10-year and 15-year TCO variants express a similar trend, although here the NPV is positive for both variants. Thus, the statement above that V1 has a “temporary” loss, the result is much more positive for V2.

This result is primarily caused by significantly higher annual recurring benefits for the V2 variant, which are roughly 2.2 times higher (225%) than for V1 (100%). From the cost standpoint, the acquisition costs are very similar (the relative difference is 10% in favor of V1), but the operating costs are very different. However, this cost type does not play a major role relative to the benefits and the overall cost of the solution.

One very positive factor within the VHV Frosting application opportunity is that no issues connected with the General Data Protection Rules (GDPR) need to be addressed as the data acquired has no relation to the GDPR, it is purely operating data [34,35]. Nevertheless, the possible impacts of Czech Act No. 412/2005 Coll., the Act on the Protection of Classified Information and Security Eligibility must be addressed. It especially comes into play in matters related to connecting secure devices to a source of electrical power or, for example, connecting nuclear power plants to the distribution network to provide an emergency electrical-energy supply.

Another factor that must be considered in the financial evaluation and explored from both the financial and legal standpoints is the question of the ownership of IoT devices, which can also influence data ownership. A device can either be owned by an IoT provider and merely provide IoT functionality to an IoT service recipient, or be owned by the end-customer. Within this article, we have focused on direct ownership; however, when the decision is made to rent instead, the issue of data ownership requires attention.

The main advantage when the devices are rented is that the responsibility for the devices' functionality and availability is placed upon their supplier, which is then compensated for its services through payments. This variant's main disadvantage is increased operating costs, as well as an increase to the overall costs. Thus, in summary, rental's main advantage lies in reduced acquisition costs, while its disadvantage is the increased operating costs. When the devices are rented, the provider collects devices and then offers them, and potentially adapts these devices for their renters. In that situation, it must be ensured that the data is not provided to third parties without the renter's knowledge. For these cases, the points of the contract that cover the provision of the devices and the subsequent data storage and processing must be extremely well formulated. If the issue of data is not handled in the contract, the renter can potentially face two types of problems. The first can arise if their contract is for the provision of specific, precisely defined data or its outputs: in that case, the provider usually requires further payment for any outputs beyond those specified in the contract. The second arises when the provider passes the collected data on to a third party, which then freely reaps the harvest of the renter's prior analytical work.

In the case of ownership, an initial investment is required, but it comes with lower operating costs: these are comprised of payments for the use of the communication services for transferring the data, and payments connected with maintaining and repairing the devices used. The primary

risk arising from this approach lies in the need for the servicing of devices due to wear and tear, damage, etc. Its advantage lies in the fact that if the devices have a long service life, then, large savings can be had compared to the situation where the devices are rented. The option to use subsidies from the European Union's structural funds to finance the new devices is another advantage of the ownership model. These funds can be used for acquiring the devices, but not for financing their operations. Also, complete control over the collected data amounts is yet another advantage of using the ownership model.

We will conclude by stating that the V2 variant, based on measuring glaze ice directly is the most advantageous solution for the VHV Frosting application opportunity. This variant has benefits 2.25 times larger than those for the V1 variant; additionally, its payback period is only half as long as for the V1 variant (3 years rather than 6).

Aside from economical factors, we must also consider other factors including:

- Factors from the factory point of view:
 1. Increasing customer satisfaction in case of less power outage.
 2. Reducing number of employees needed for managing problematic situations.
 3. Reducing risks of black-outs.
- Factors from the customer point of view:
 1. In case of sharing information about temperature – detailed knowledge about temperature.
 2. Reducing power outage reduces risks related to customer activities.
 3. Improving quality and stability of services reduces side effects for companies using electricity.
- Factors from the third parties' point of view:
 1. Higher profits and smaller costs generate bigger profit, which is related with higher taxes which are paid to the government.

Author Contributions: All of the authors wrote and revised the paper. P.S. completed the data for analysis. L.N. realized sources overview and formatted the paper. M.M. and P.D. designed the research schema, evaluated data sources and calculated the financial effects.

Funding: This research was funded by grant of Faculty of Informatics and Statistics of the University of Economics, Prague number IP400040.

Acknowledgments: Paper was processed with contribution of the Czech Science Foundation project GAČR 17-02509S and with support from institutional-support fund for long-term conceptual development of science and research at the Faculty of Informatics and Statistics of the University of Economics, Prague (IP400040).

Conflicts of Interest: The authors declare no conflict of interest.

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