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Economic and technological aspects of using IoT for sustainable environment management. The case of IoT Wildfire Detection Systems -

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Abstract: *The paper has as main goal to evaluate the feasibility of a Next Generation Wireless Sensor Network System for Forest Fire Protection as an Internet of Things (IoT) Application. This new solution for forest fire monitoring and protection could be targeted at both state and private organizations, which are located in regions where fires represent a threat. After a broad economic and technical examination, the article will show that this type of IoT system can offer an efficient approach for reducing economic and biodiversity loss, while helping to prevent human casualties.*

Key-words: *Internet of Things (IoT), Sustainable Economic Development, Environment Management, Wildfire Detection, Wireless Sensor Network.*

1. Introduction

Within the current turbulent global economic, demographic, social and ecologic context, governments, local administrative authorities, researchers and commercial companies or even individuals have to recognize the importance of the resources contained in the forest environment - not only from the perspective of the biodiversity, but also from the point of view of the economic resources which forests enclose. Therefore, any major threat posed to this essential component of the environment should be identified, studied and fought through the most efficient and modern economic policies and technological means.

One of the most dangerous phenomena, which jeopardize forests, is represented by **forest fires**. A forest fire is any form of unrestrained fire that erupts in a forested area. Forest fires have proven to be a massive form of destruction for humankind, especially when not countered through appropriate measures and strategies. The most important measures for fighting forest fires are:

1. Prevention.
2. Prediction.
3. Suppression.

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United Nations Environment Programme catalogues **wildfires** - and therefore, forest fires - as “on-going and rapid/sudden-onset environmental threats” (UNEP, 2012).

Forest fires create a hazard to lives and properties and are often connected to secondary effects such as landslides, erosion, and changes in water quality; therefore, the UNEP considers that **early warning systems** are of great importance for preventing or limiting environmental and economical damages.

Early Warning (EW) is defined as *“the provision of timely and effective information, through identified institutions, that allows individuals exposed to hazard to take action to avoid or reduce their risk and prepare for effective response” (UN, 2006),* and it implies the combination of four main elements (according to the United Nations’ International Strategy for Disaster Reduction - ISDR):

1. **Risk Knowledge and Risk Assessment**
2. **Monitoring and Predicting** - in order to provide appropriate estimates of the potential risk encountered by communities, economies and the environment.
3. **Disseminating Information** - through electronic communication systems in form of reliable, synthetic and simple warning messages.
4. **Response** - according to appropriate action plans.

Nevertheless, extant research on EW emphasizes, *“predictions are not useful, however, unless they are translated into a warning and action plan the public can understand and unless the information reaches the public in a timely manner”*. “When monitoring and predicting systems are associated with communication systems and response plans, they are considered early warning systems.” (Glantz, 2003)

The main topic of the paper is primarily correlated with the overall objectives of **environmental protection and management** related to **developing a sustainable management of the natural resources while preserving biodiversity,** and **evaluating modern technologies for environmental monitoring and risk assessment, used to predict the regional impact of climate changes on forest areas, based on numerical data.**

*The assessed economic and technical solutions envisaged for the **Wireless Sensor Network (WSN) System for Forest Fire Detection** are oriented toward adapting and evolving the newest technological achievements in the field of smart sensors, wireless networking infrastructure, machine-to-machine communications, advanced next generation electronic communications networking and power harvesting, for creating a **composite heterogeneous modular WSN Forest Fire Detection System, which could provide forest environmental monitoring and fire detection services at lower costs than existing solutions**, while having the **advantage of higher accuracy, shorter detection time and increased ease of use**.*

2. The context and the link between IoT and sustainable development

Information and communication technologies (ICT) is an all-encompassing concept, which covers the diverse digital technologies used for manipulating information, such as computers and mobile phones (Goswami, 2014).

David Souter - the Managing Director of ICT Development Associates - considers that "computerization, the rise of mass markets for telecommunications, the Internet, and innovations like cloud computing are fundamentally altering the ways in which goods and services are produced and consumed, the availability of information to people in different contexts, and aspects of relationships among individuals, groups, and governments", and therefore the pervasive use and rapid evolution of IoT and new communication technologies are generating the need for a revised definition of sustainability. (Souter, 2013)

Researchers like Shubham Goswami (2014) emphasise that the link between the advance of information and communication technologies and the quest for sustainability is a developing but rather uncharted research area. Moreover, the sphere of ICT for sustainability (ICT4S) sometime intersects with other fields of research like sustainable HCI (Human Computer Interaction), environmental informatics, greening through IT, and cleanweb.

Mr. Houlin Zhao, ITU Secretary-General, asserted in ITU's "Harnessing the Internet of Things for Global Development" report from 2016 that: "The Internet of Things is not a single, unified network of connected devices, but rather a set of different technologies which can be put to work in coordination together at the service and to the ultimate benefit of people in both developed and developing economies. This set of Internet of Things technologies is realizing a vision of a miniaturized, embedded, automated environment of devices communicating constantly and automatically". (ITU, 2016)

Furthermore, the resolution entitled "Transforming our world: the 2030 Agenda for Sustainable Development" (adopted by the United Nations - General Assembly on 25 September 2015) highlights the evident potential generated by the dispersion of ICTs and the evolution toward global interconnectedness - both being able to fast-track human progress, to eliminate the digital divide and to foster knowledge societies. (UN, 2015)

Mr. Chuck Robbins, CEO of Cisco Systems, deems that: "Today, the Internet of Things is improving the day-to-day lives of citizens around the world. In cities from Barcelona to Songdo to Rio de Janeiro, Internet Protocol (IP)-connected sensors are monitoring traffic patterns, providing city managers with key data on how to improve operations and communicate transportation options. Similar information flows are improving hospitals and healthcare systems, education delivery, and basic government services such as safety, fire, and utilities. Sensors and actuators in manufacturing plants, mining operations, and oil fields are also helping to raise production, lower costs, and increase safety". (ITU, 2016)

Goswami (2014) stresses that Sustainability and Sustainable Development (SD) has its origins in the proceedings of the UN Conference on the Human Environment, the Brundtland Commission and the Earth Summit in 1992. According to the World Commission on Environment and Development (1987), Sustainable Development is considered to be the development that "meets the needs of the present without compromising the ability of future generations to meet their own needs".

While the adoption of Sustainable Development Goals in September 2015 signified the beginning of a new period in international development (combining economic, social and environmental objectives within a broad global approach covering the fifteen years - from 2015 to 2030), David Souter considers that: "Setting global targets that encompass the complex relationship between ICTs and sustainability could be very difficult. [...] Shoehorning sustainability into a set of targets in the way that development was shoehorned into a set of poverty reduction targets could be misguided." (Souter, 2013)

Other researchers (Goswami, 2014; Robbins, 2016; ITU, 2016) perceive the new Sustainable Development Goals as an opportunity for augmenting the role of ICTs as cross-cutting enablers of development across the entire 2015-2030 Sustainable Development Program. These positive effects have evolved as technology has become more sophisticated, user numbers have increased, more bandwidth has become accessible, and new services have been launched. Additional on-going ICT advances (e.g. cloud computing, Machine to Machine - M2M communications and the Internet of Things) suggest that ICTs will have even larger impact on development implementation and outcomes over the next fifteen years.

3. Economic opportunities and practical relevance of Forest Fire Detection and Protection Systems

Extant international research at global level emphasises that: "Due to warmer climates and human activity, fire incidence is increasing around the world." (TEEB, 2012)

The United Nations Environment Programme (UNEP, 2012) estimates that, globally, biomass fires are burning yearly (in average) between 3 and 4.5 million km^2 (depending on years and detection method used).

The effects of biomass fires are widespread, affecting both local and global environment - with consequences related to local biodiversity, soil, as well as to the production of large quantities of Green House Gases, thus affecting the global climate. (Chatenoux and Peduzzi, 2013)

Therefore, the **importance and effects of deforestation** are a major concern for international, regional and local organisations: in 2008, "The Economics of Ecosystems and Biodiversity" (TEEB) initiative was launched in response to a proposal by the G8+5 Environment Ministers to develop a global study on the **economics of biodiversity loss**.

The TEEB 2008 report showed that our world is in grave danger if the world population continues to consume the natural resources available in the same rate as we do now. It is estimated that the **world economic losses due to deforestation** represent \$2 to \$5 trillion, annually - a figure calculated by adding the value of the various services that forests perform such as providing clean water and absorbing gigatons of carbon dioxide. Reports (TEEB 2010) have approximated that the world's forest ecosystems currently store between 335 – 365 gigatons of carbon, and an additional 787 billion tons in the top one metre layer of soils.

Scientists draw attention to the fact that the economic losses reported are primarily related to the value of properties or timber, but **forests also provide other services**, like: "carbon storage, production of dioxygen (O^2), production of biomass (used for timber, fire wood, building), recreational value, intrinsic and support to biodiversity, protection of water sources, reduce soil erosion, production of pharmaceutical products. Forests also participate to local climate (colder temperature, darker albedo and rougher surface can lead to higher precipitations), shade of forests are protecting water sources, humidity content in the vegetation is a source of inertia for regulating dry periods". (Chatenoux and Peduzzi, 2013)

Taking into account the benefits generated by the world's forests, preserving them through forest fire protection systems and extending their area is becoming a priority not only for governments but is now acknowledged as a **business opportunity** in relation to **carbon credits** (e.g. in TEEB in Business 2011-Chapter 5).

The problems for the biodiversity and ecologic system are of great concern for governments as the impacts are clearly significant as noted in the previous paragraphs. Accordingly, countries in the EU, US and other entities affected by fires have **allocated distinct budgets for addressing the causes, effects, and prevention of fires.**

The World Bank is another large financer to support the world's biodiversity, which has funded over the last 15 years biodiversity projects of more than \$3 billion and cooperated with the World Wide Fund (WWF) and Program on Forests (PROFOR) to fund projects for forestry preservation. (World Bank and PROFOR, 2016)

Business opportunities also exist with commercial companies that manage large areas of forests for legal logging, olive groves, farming, etc. These companies prosper well if the fires destroying their assets are prevented as much as possible. Hence, **elaborating a suitable solution for forest monitoring and handling the fires in real-time** over small or large forested areas - in an effective and cost efficient manner - is still not fully explored nor found, as it will be detailed in the following sections.

These opportunities for business in the field of **forest fire monitoring and protection systems**, combined with the availability of funds from the governments and institutes - on the backdrop of novel technological developments and growing social collaborative mechanisms - represent suitable **premises for creating a**

completely new market, in which the **first-mover advantage** gained by the initial significant occupant of that market segment will ensure a strong foothold in the new market.

The prospective **applications with market potential of such an IoT fire detection system** are mainly related to:

- **Rendering marketing services** regarding the implementation of an elaborated Marketing Plan and Marketing Mix for forest environmental monitoring and forest fire risk assessment and detection services based on Social Media Networks;
- **Licence contracts** on bases of the patent applications submitted;
- **Production and marketing of the developed electronic components** (e.g., Wireless Sensor Network Topology Control Module; Wireless Sensor Energy Control Module; Low-power, low-noise power management block for the readout module and selected sensors; Various types of Modular Wireless Sensors for forest fire protection; Modular Wireless Communication Multiple Sensor Platform);
- **Production and marketing of the developed software applications and components** (e.g., Firmware for transfer of data from readout module to the graphical interface for post-processing of data; Social Internet of Things (SIoT) Software Application for forest fire detection services based on wireless sensor networks (WSN) and Social Media Networks integration);
- **Service rendering through the elaborated Wireless Sensor Network System for Forest Fire Detection.**

4. Assessment of the State of the Art for Forest Fire Detection and Protection Systems

The essential requirements of an early warning system for forest fire protection are related to the fact that the earlier and more accurately we are able to predict short- and long term potential risks associated with natural and human provoked wildfire hazards, the more likely we will be able to manage and alleviate a disaster’s impact on society, economies, and environment.

We have already studied several existing systems for forest fire protection, but none of them is effective enough in terms of sensitivity, range, power and cost. Drones, satellites, towers with infrared cameras are expensive, require a lot of maintenance and are not reliable since they produce many false alarms or the data arrives when the fire has already spread. Several groups have proposed systems, which have been optimised for power consumption, relatively good sensitivity or area coverage, but none solves the problem from the point of view of the cost and flexibility of the system.

The fire protection problem can be tackled at three different levels: Satellite imaging, areal and ground surveillance, and sensor monitoring. As areal and ground surveillance is mostly relying on people, there are no important advances in technology to be identified. Therefore, we focused only on the satellite imaging and sensor monitoring solutions.

4.1. Satellite detection systems

The U.S.A Forest Service predicts fires with a variety of tools, including remote automated weather stations. Nevertheless, these stations are expensive and distributed. Often, the dense forest prevents inspection by satellites sensors rendering these stations useless.

Many fires start under the dense canopies of high tree and by the time a satellite sensor detects the presence of fire its extent and intensity is difficult to control or to send human or aerial fire brigades to the place.

The NOAA Satellite and Information Service (for details, see: http://www.ssd.noaa.gov/PS/FIRE/hms.html) is an interactive system that allows trained satellite analysts to integrate data from various automated fire detection algorithms with moderate resolution imaging spectroradiometeres and Meteorological Satellites. The result is a display of the locations of fires and smoke plumes. The information produced by monitoring systems like this is used as a general guidance and for strategic planning, but not for real time information of the fire. Usually the information provided by such systems has to be corroborated by other means before a tactical decision to fight the fire is made. Reports of systems such as these are usually updated during a certain time of the day. The MODIS Rapid Response System (Moderate Resolution Imaging Spectroradiometer) is a near real time system, which allows the tracking of dust and ash in the atmosphere. Still the response time of the system is in the order of hours and only upon request.

4.2. Sensor detection techniques

Other detection techniques have also been explored by some institutions, namely optical methods including infra-red and visible light, gas detectors (hydrocarbon detectors, smoke detectors (particulates and mainly non optical) and Radio Frequency Techniques (Radar).

Nevertheless, such techniques are not fully reliable. Phenomena such as atmosphere interference to certain frequencies represent a major problem. Other examples include camera networks that can be installed in different positions in the forests but these provide only line of sight pictures and weather condition and/or physical obstacles may have an effect on their accuracy (Alkhatib, 2013).

Gaseous emissions are also investigated mainly for decomposition products prior to a fire. Radioactive emission prior to a fire is also a field of research. It is well known that plants absorb many elements in concentrations up to 109 times those found in their environment; therefore, it is possible that some detectable radioactive release of these materials is done upon combustion. All these techniques are in the research stage and yet not reported successful results.

Although none of the previously mentioned fire detection method fully covers the essential requirements of an early warning system for forest fire protection in an effective and cost efficient manner, many researchers have concentrated to conceive proprietary optimised fire detection systems. In this respect, mainstream fire detection research has examined the option of wirelessly connecting arrays of standardised sensors for a better coverage and scalability of the system.

The new technology called **Wireless Sensor Network (WSN)** is currently receiving more attention from researchers: Buratti (2009) considers that a WSN is *"a network of devices, denoted as nodes, which can sense the environment and communicate the information gathered from the monitored field (e.g., an area or volume) through wireless links. The data is forwarded, possibly via multiple hops, to a sink (sometimes denoted as controller or monitor) that can use it locally or is connected to other networks (e.g., the Internet) through a gateway. The nodes can be stationary or moving. They can be aware of their location or not. They can be homogeneous or not"*

This technological evolution is also covered, in a broader manner, by international organisations like the ITU, which in its "ITU-T Technology Watch Briefing Report 2008" outlines the main characteristics and fields of application of so-called "Ubiquitous Sensor Networks (USN) - including the most important components of a USN:

• *Sensor Network: Comprising sensors and an independent power source (e.g., battery, solar power). The sensors can then be used for collecting and transmitting information about their surrounding environment;*

• *USN Access Network: Intermediary or "sink nodes" collecting information from a group of sensors and facilitating communication with a control centre or with external entities;*

• *Network Infrastructure: likely to be based on a next-generation network (NGN);*

• *USN Middleware: Software for the collection and processing of large volumes of data;*

• *USN Applications Platform: A technology platform to enable the effective use of a USN in a particular industrial sector or application."*

A number of researchers (Alkhatib and Baicher, 2012) only offer a conceptual repertoire of WSN-related issues like: factors that will influence the design; network services; and bandwidth choices for Wireless sensor network; others (Tariq et al.- 2012, Abuarqoub et al. - 2012, Kazi - 2013) discuss more specific issues like assessing data reliability and Information Extraction (IE) from Mobile WSNs or data reduction strategies (Risteska Stojkoska et al., 2012).

The latest advances in WSNs sustain our conviction that the use of WSNs may constitute a promising framework for a solution to the previously mentioned requirements for building real-time forest fire protection systems. Extant literature (e.g., Antoine-Santoni et al. - 2009, Hariyawan et al. - 2013) emphasises the progress through practical implementations of WSN based fire detection systems incorporating sensing modules that can *"sense a variety of phenomena, including gas temperature and relative moisture content, two essential parameters in fire detection. Sensor nodes can operate for months on a pair of AA batteries to provide constant monitoring during the fire season. Moreover, recent protocols make sensor nodes able to organize themselves into a self configuring network, thus removing the overhead of manual setup"*. (Antoine-Santoni et al., 2009)

The **feasibility of using wireless sensor networks for forest fire monitoring** is illustrated in specialised research projects, which show different small-scale implementations of proprietary sensor solutions and the related WSNs. Thus, a medium term experimentation is described by Larios et al. (2013) in the article *"Five Years of Designing Wireless Sensor Networks in the Doñana Biological Reserve (Spain): An Applications Approach"* in which they demonstrate the advantages of WSN technology, through some prototypes deployed in the last five years in the Doñana Biological Reserve (an important protected area in Southern Spain). They reveal the enormous potential of *"using machine learning in wireless sensor networks for environmental and animal monitoring because this approach increases the amount of useful information and reduces the effort that is required by biologists in an environmental monitoring task"*. Different types of sensor solutions are covered by works like *"Early forest fire detection by vision-enabled wireless sensor networks"* in which Fernández-Berni et al. (2012) present the 4 year development of a vision-enabled wireless sensor network node for the reliable, early on-site detection of forest fires. Their contribution covers the elaboration of a robust vision algorithm for smoke detection to the design and physical implementation of a power-efficient smart imager tailored to the characteristics of such an algorithm.

Other authors like Antoine-Santoni et al. (2009) analyse the issue of sensor protection during fire. In their paper *"Performance of a protected wireless sensor network in a fire. Analysis of fire spread and data transmission"* they present the WSN technology as a *"reliable solution for capturing the kinematics of a fire front spreading over a fuel bed"* and identify ways of avoiding the destruction of WSN-motes by the fire and experimenting sensor protection through thermal insulation.

Some terrain-adapted WSNs are also described by authors like Byungrak Son et al. (2006) in *"A Design and Implementation of Forest-Fires Surveillance System based on Wireless Sensor Networks for South Korea Mountains"*: they compare existing "classic" surveillance systems (that use a camera, an infrared sensor system and a satellite system) with a newly developed forest-fires surveillance system for South Korea Mountains. Their FFSS consists of WSNs (which measure temperature, humidity, and detect smoke), middleware and web application. They identify the need for future research about effective modes of communication that facilitate no data loss.

The **common denominator** of all research papers is the fact that **real time early detection** and **accurate location** are two crucial points when it comes to preventing forest fires from spreading. According to INSA (2000), *"the intervention of fire suppression resources becomes much more efficient if an alarm signal containing the geographical coordinates of the fire is delivered within a* ***time interval of 15 minutes****"*. Others (Aslan et al., 2012) consider that *"a forest fire usually grows exponentially and it is crucial that the fire* ***should be detected and interfered*** *in about* ***six minutes*** *to prevent the fire from spreading to a large area (National Fire Danger Rating System - NFDRS, 2011)"*.

Summarizing the identified disadvantages of the existing solutions and research concepts, the **paper's contribution to the progress beyond the state of the art** is mainly represented by the following three elements:

a.) Most systems **sense fire by detecting smoke**, which is **not a sufficiently effective solution** because, by the time the available systems detect smoke, it is already too late, the fire has already spread to a large area and has caused enough damage. Even more, the systems developed so far detect only one type of fire, the one that goes up through the forest trees, but there are other types: through dried leaves in the ground, canopy fire (that spreads quite fast) and others. Even more, many of these systems only **detect fire on open areas** (not through a dense forest) - only when the smoke column has passed the top of the trees the system is able to generate a signal. Another problem is represented by **false alarms**: the systems available detect many signals as smoke and, in fact, they are only atmospheric changes, no real fires. Although there are some systems with better performance, the best systems are extremely expensive, based on infrared cameras with a lot of filters on top of very high columns to cover large areas and that require specialized people to constantly monitor the signals and discard false alarms. Therefore, **a suitable goal is** that **a new system should be able to detect fire through moderate dense forests, in a very early stage, will learn itself to discard false alarms, and will be very easy to operate and to be deployed by the users, robust and versatile.**

b.) Most systems are **not optimised for a specific sensor or a group of sensors** to detect either smoke, infrared or light signals, meaning that the signal-to-noise ratio of the systems is not optimised and therefore a lot of important information is lost due to a poor readout block design (using only commercial devices). Hence, **in conjunction with a proposed two-fold market segmentation strategy**, **a high-performance readout block** should be developed - one that can, as early as possible in the signal path, discard false signals (or noise) so to really detect only those coming from fire. A **readout module optimised for noise and power consumption** will also be a big differentiator. The system should be clever enough to control its duty cycle of readings so to save battery power and extend battery lifetime. In the dry season, when most fires happen - it should be working continuously (with approx. 50-50 duty cycle), in winter or rainy seasons - it should be only 10% or even much less. As far as we have investigated, no other system does that.

c.) The other systems are **only made for a specific type of terrain** (either large open areas, or specific, narrowly determined, types of terrain) but no system considers and covers different type of landscape simultaneously (mountains, hills, open areas, glens, ravines, etc). The proposed alternative system should be made in a way that the **initial setting is not fixed but it optimises itself after some time of operation** - this **will allow for a flexible system** that requires more modules for dense forest areas and less modules for open areas where even a relatively low-performance sensor can accomplish the task.

5. Original and innovative contributions of the proposed solution

Alongside the various technical and scientific improvements proposed and already stated in the previous sections - which cover the **development of a high-performance readout block** and an **optimised readout module for noise and power consumption** or our concept that the **initial setting of the system is not fixed but optimises itself** after some time of operation - the solution envisaged by this paper **innovates also from a marketing perspective by aiming at** a **two-fold market segmentation strategy, implemented within the new digital environment of Social Media Networks**:

- On one hand, the new forest fire protection system could cater for **hi-end users with high demands through new optimised sensors** and

- On the other hand, **the system could also market the future developments** (soft and hard) as an "**open**" **platform for modular large scale fire protection systems** in which **different types of private individual users** can "participate" through sharing fire protection relevant data from own devices (e.g. smartphones, tablets, Automobile Multimedia/Sensor Systems, individual sensor-based accessories etc.) through Social Networking Applications - thus **building a Social Internet of Things (S-IoT) Application**.

We consider that the corresponding benefits will be greater than the outcomes of choosing only one segment or a specific solution - especially if we think of the synergies that could be obtained and the **potential of implementing a "Smart Data Mining Solution" based on the information of large numbers of users connected with heterogeneous devices/sensors to a future cloud-type Integrated Platform for Fire Protection.**

Another opportunity would arise from the fact that **the proposed solution can create a whole new market for third-party S-IoT enabled sensor-accessories**, which can generate traction for proprietary services and products (soft- and hardware).

6. Conclusions

The expected results can be synthesized by describing the **synergic effects of combining the power of M2M communications between smart sensors with the dynamic environment of Social Media** on the background of the need to implement - in the field of forest environmental monitoring - of competitive business strategies, which not only bring profit to the organisations, but also have to follow the guidelines of modern sustainable development (e.g., the quest for resource-saving, innovation, knowledge management, economic flexibility and agility).

Therefore, **companies and organizations operating in the domain of forest resource management could profit from the novel principles of the WSN SIoT Forest Fire Detection solution elaborated through this research paper and take advantage of the opportunities** offered by the rapidly developing socio-economic and technological environment (encompassing the pervasive and powerful ICT deployment, increasing Social Networking adoption, economic and regulatory changes within the Telecom sector, etc.) **and put into practice the newly designed technical solutions and business models based on novel marketing concepts and implemented within the new electronic communications paradigm of computing mobility and network functions virtualisation.**

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