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The Concept of Multiple Impacts of Renewable Energy Sources: A Critical Review

Michaela Makešová * and **Michaela Valentová**

Department of Economics, Management, and Humanities, Faculty of Electrical Engineering, Czech Technical University, 166 27 Prague, Czech Republic; Michaela.valentova@fel.cvut.cz
* Correspondence: Michaela.lachmanova@fel.cvut.cz

Abstract: Reaching climate neutrality by 2050 is one of the main long-term objectives of the European Union climate and energy policy, and renewable energy sources (RES) are integral parts of this transition. RES development results in many effects, direct and indirect, linked to each other, societal, local and individual, i.e., "multiple impacts of RES" (MI RES). These effects need to be carefully assessed and evaluated to obtain the full picture of energy field transformation and its context, and enable further development of RES. Nevertheless, the MI RES concept is often presented misleadingly and its scope varies throughout the literature. This paper provides a literature overview of the methodologies of this concept and presents a new concept of MI RES, respecting the difference between effects resulting from the implementation of RES and ultimate multiple impacts. We have summarized the effects into four groups: economic, social, environmental, and technical, which all lead to group of ultimate multiple impacts. Finally, we provide the complex overview of all MI RES and present the framework, which is used to analyze the multiple impacts and effects of RES and to show how the RES development leads and contributes to these impacts and effects. The concept is recommended to be considered in designing a robust energy policy by decision-makers.

Keywords: multiple impacts of RES; energy policy; co-benefits; employment; air pollution; GDP; energy poverty

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1. Introduction

Worldwide society development, technology, and science evolution, industry, and hence the growth in living standards, are accompanied by a rise in energy consumption [1,2] resulting in a growing need for resources, especially non-renewable energy resources. Particularly, depletable fossil fuels were increasingly consumed in recent decades with all the resulting negative consequences, i.e., the exploitation of natural resources and negative impacts on the environment and human health. Renewable energy sources (RES) are considered one of the main drivers to reverse this negative course, and the share of RES, especially in the power energy sector, has increased substantially in the last decade [3].

The Paris Agreement provides a global framework for preventing significant climate change by limiting global warming to well below 2 °C and continuing the intentions to reduce it to 1.5 °C [4] by emphasizing renewable energy as one of the solutions. The European Union (EU) now aims at a climate-neutrality by 2050, with an immediate target of 32% RES share on gross energy consumption by 2030 [4,5]. The expected renewable energy expansion requires a fundamental transformation of our energy system. All effects of these truly transformative changes should, therefore, be thoroughly explored and evaluated.

It was widely acknowledged that the increasing share of renewable energy was not associated only with the greenhouse gas emissions (GHG) decrease and natural sources savings. A higher RES share is also associated with wider societal, environmental, and economic impacts (we deliberately use the term impacts, as they can be both positive and negative, although the positive impacts prevail, as we show later in the paper) [6,7]. This concept of so-called "multiple impacts" of low-carbon technologies, specifically of renewable energy sources, is not new. Despite a growing research on multiple impacts of renewable energy sources (MI RES), the question of what this term exactly means as a concept and how it needs to be taxonomized and evaluated has not been answered clearly yet. The scope and main objectives of MI RES vary throughout the literature and the term is often used differently [1,8,9]. Therefore, the core objective of this paper is to clarify the concept, summarize the existing MI RES, and provide a critical analysis, categorization, and quantification of the potential MI. We present a novel view on unforeseen effects of the RES development leading to the ultimate multiple impacts of RES. To follow this target, we provide the literature overview with a combination of semi-systematic and integrative approach [10], which uses systematic research in articles and other published texts (see Section 3) by using keywords and qualitative and quantitative analysis of the literature.

In Section 2, the paper provides a short assessment of the trends in the energy sector, which can serve as a motivation for further research. It allows us to fully follow a renewable energy development and possible effects, differentiating among fields of impact. The third section overviews the methodology of this paper, the fourth section reviews the conceptual approaches and definitions of MI RES, methodologies evaluating RES implementation and offers an MI RES taxonomy. The fifth section follows the proposed categorization to assess, quantify, and show the relationship between the RES development and the mentioned impacts. The last section concludes our presentation and provides some policy implications.

2. Trends in the Energy Sector

The worldwide development in technology, science, industry, and hence the overall growth in living standards has been interconnected with the rise in energy consumption, not only in the power energy sector but also in the transport and heating sectors [2]. On the one hand, global direct primary energy consumption increased from 100,000 TWh to 140,000 TWh within the 2000–2020 period [2] and according to the World Bank, 90% of the world's population had access to electricity as of 2018, and 94% of the global population should have access to electricity by 2030 [11]. On the other hand, this increasing energy consumption affects the environment. Since 2000 the global CO_2 emissions have been still increasing, excluding the 2009 crisis drop, four flat years 2013–2017 and 2020 COVID-19 pandemic-related "record fall" [12], the average annual increase in a global CO_2 emission level is 1.4% (from 25.4 billion of tons of CO_2 in 2000 to 34 billion of tones in 2020). At the same time, methane emissions, particularly from oil and gas industries, have been also growing [13–15]. Due to this fact, new sources must be used cost-effectively and must have a minimum negative environmental impact. Renewables are considered as one of the possible solutions as a part of the green, low-carbon economy, which is defined by UNEP (United Nations Environment Programme) as "one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities" [16].

The last years were extraordinary from the perspective of renewable energy and energy efficiency targets and development. Following the Paris Agreement [4], many countries now aim to avoid GHG emissions as soon as possible to achieve a climate-neutral world by the mid-century, using low-carbon solutions [17]. For instance, China has pledged carbon neutrality recently [18] and the President of the United States of America also declared the acceptance of the Paris Agreement in January 2021 [19]. The European Union has now adopted an ambitious target of climate neutrality by 2050 and a RES share of 32 % by 2030 [5]. It is a continuance of a long-term strategy for clean and secure energy in Europe, first accepted in 2007. The first GHG, RES, and energy efficiency targets aimed at reducing the dependence on imported energy, increasing the EU energy security, developing employment, and making Europe more competitive. The compatibility of these three main targets of reducing emissions and consumption and increasing production from renewable sources seemed to be taken for granted [20]. These goals were set more ambitious and extended in 2015 with the Governance on the Energy Union [5], and lastly, in 2020 to present the aforementioned goal of climate neutrality. New renewable technologies will play a crucial role in achieving the EU 2050 targets [21], since the increase of total energy consumption is followed by the increase of the RES share, partly replacing fossil fuels [5].

Besides the constantly growing trends in decarbonization, which will be partly fulfilled by an increasing share of RES, and improving energy efficiency, other trends are observed, as well. Sector coupling, i.e., "*a coupling of the power sector to other sectors, i.e., residential heating, transport, and industry*" [22] which are still primarily based on fossil fuels, starts coming to the forefront [23–25]. The sector coupling concept emphasizes the role of electricity, and therefore renewables, due to the sharp increase in electricity exploitation within the sectors of energy production, transport (electromobility), and residential energy consumption (heat pumps, PV). As the role of renewable energy increases, the boundaries between the sectors will become thinner and thinner, and the role of new sources replacing renewables will be even more significant.

To cope with this challenge and to achieve the mentioned targets and climate objectives, strong policies facilitating the necessary RES development should be widely supported. To be well designed, the policies should be based on thorough reflection and understanding of the whole-societal benefits and costs of RES and GHG mitigation. Multiple Impacts of RES are the effects accompanying the RES development both at regional, national, and global levels. The effects, e.g., improved air quality, increased GDP or employment, can be generated by various measures, originally aiming only at reducing GHG emissions. However, these co-benefits are not often taken into account when designing and promoting new energy policies [7]. The main reason is the difficulty to assess MI RES and by the absence of the exact clarification of the direct RES contribution. Considering the multiple impacts of the energy system, environmental and economic benefits of clean energy, policymakers can more fully understand the range of costs and benefits of these potential actions [26]. Hence, this paper, aims to contribute to this research gap by categorizing, assessing, and quantifying the MI RES.

We can see that several approaches (analyses) aim to include the co-benefits or additional benefits to the evaluation of the RES development (Life Cycle Assessment—LCA, IAM models and to apply rigorous approaches to evaluate the benefits (Multiple Criteria Decision Analysis—MCDA). In our paper we provide the definition of multiple impacts, and an overview and framework which can be used as inputs in these detailed analyses.

3. Methodology

This section is devoted to the methodology of the paper. As main methodology, a literature review and further qualitative and quantitative analysis were used. Following Snyder [10] who provides complex evaluation and comparison of the different approaches of literature review and presents several examples of existing guidelines for conducting a literature review, a combination of semi-systematic review and integrative approach [10] was used here. The reason for this approach lies in the purpose of our paper, which is to systematically overview the research area and track the development of the methodologies of MI RES over time.

Due to the broad character of the field we used a review of articles and books to provide the taxonomy and framework of MI RES. First we designed the review by setting the keywords "multiple impacts of renewables", "multiple benefits of renewables", "non-financial benefits of renewables" etc. to collect the information about MI RES and to cover;

- the different methodologies trying to grasp the whole issue comprehensively, and
- case studies describing multiple impacts defined in our research.

Secondly, the review was conducted by providing pilot test of available literature to overview the field. Several methodologies presented in the Section 4 show that the approaches are not consistent and do not cover all the effects of RES development. Further analysis of the methodologies and case studies dealing with individual effects enabled creation of complex overview of all effects and conclusion of ultimate Multiple impacts of RES, which are presented in the following text.

4. Conceptualization of MI RES

There is no single definition of MI RES. Similarly, there are many different views of the whole concept and methodical approaches for assessing MI RES for heating, electricity, and transport. This section aims to understand the development of the MI RES concept, presenting the main approaches to MI RES. Based on a thorough evaluation of the MI RES framework and various approaches to the MI RES taxonomy, we offer our own categorization that is further used to assess the MI RES. The prevailing argument and the main purpose for the RES installation tend to be CO_2 or GHG production decrease, as shown by e.g., [1,3,27–34] and the positive impact on the environment by replacing fossil fuels in electricity and heat production. Thus, particularly the studies, assessing the primary benefits of renewable energy, focus on the evaluation of environmental impacts of the RES implementation [35], GHG emission decrease, or evaluation of water consumption [30,36], trying also to provide multi-evaluation assessments [37,38] which differ sector by sector (electricity production, transport, etc.).

Nevertheless, it started to be clear with further development of RES that renewable energy implementation brings other benefits, not only the obvious environmental ones. Already in 2000, Dincer [31] claimed that "*renewable energy sources and systems can have beneficial impacts on the essential technical, environmental, economic, and political issues of the world*". According to Bruhn-Tysk [34], environmental impacts divided into local and global impacts—direct and indirect—should be extended by the impact on natural resources and societal sustainable development. Also, other analyses revealed that implementing renewable energy, energy savings measures, and more efficient technologies could result in socio-economic benefits. It could contribute to the development of employment and result in large profits on exports and positive health effects [39]. According to UNEP [16], the greening economy "*not only increases wealth, but also produces higher GDP, contributes to poverty alleviation, job creation, and better management of natural resources*". Thus, RES were expected to contribute substantially to sustainable development by reducing energy consumption, decreasing climate change effects, limiting environmental degradation and related human health concerns, and promoting economic development [26]. 100% Renewable energy systems with all these benefits can be further installed [40] and may be economically cost-effective compared to the conventional sources. Therefore, for the future RES development it is necessary to make all these impacts an inseparable part of the decision and policy-making processes, which has not currently happening in a systematic way [41].

Due to the recent expansion of renewable energy and energy-saving measures, studies trying to cover comprehensively and systematically non-financial benefits have been arising. We present several major studies to understand the MI RES concept development.

The concept of multiple impacts first emerged in the field of energy efficiency (MI EE), where the research was conducted very deeply [1,8,9,26]. Although the MI EE concept has been elaborated in detail and is more involved in the process of policymaking, the research in the MI RES has not been developed so broadly [8,42]. In the literature dealing with MI EE [41,43–47], multiple impacts have been differently assessed as "positive externalities", "co-benefits", "ancillary benefits" and "non-energy benefits"—terms, which can be replaced with "multiple benefits" According to the International Energy Agency (IEA) [42], which was the first to use the term "multiple impacts" of energy efficiency measures, multiple impacts represent a real value of green investment across all economies. The main aim of the IEA approach is to identify and assess all the multiple impacts of energy efficiency investment, not being categorized, but estimated, proved and assessed as benefits. This approach is detailed and appropriate to assess the multiple impacts of energy efficiency measures and can be transformed into a renewable field. The assessed multiple impacts are mainly [1,8]:

- Enhanced energy access, improved energy security, decreased energy prices, energy savings,
- Improved health and welfare, improved air quality, emissions savings,

- Households savings, increased asset values,
- Increased productivity, public budgets, and economic benefits.

We conclude that some of these impacts are direct (energy savings—both local and global; household energy, and monetary savings and increased asset values) and some of them are indirect (enhanced energy access, improved air quality, etc.). These indirect benefits and their direct link to the RES development (energy efficiency measures, respectively) are hard to prove, which we consider as the main challenge of this task.

The IEA [1] defines the term "multiple impacts", as "*non-energy benefits in the energy efficiency field*". This is almost in line with [8] which extends the IEA approach by using the MI EE term to express "*all private and general benefits and costs related to the implementation of renewable energy use which are not direct private benefits or costs involving financial costs and benefits*". These approaches are very similar to [48] that focuses only on the positive externalities of the RES investment dividing them into energy security and diversity impacts, environmental protection impacts and public health improvement, energy access and affordability, and economic growth. In this approach, it is evident that the benefits are considered in general, which can thus have positive impacts on individuals.

All these benefits, if the impacts are positive, can be enjoyed by different stakeholders. The impacts differ according to the stakeholder group, distinguishing positive MI EE on [1]:

- macroeconomic impacts
- public budgets
- health and well-being
- industrial sector
- energy delivery

We can see that all these approaches are quite similar; the multiple impacts are considered here as indirect public and individual benefits.

One of the first complex approaches using the term "multiple benefits" related to renewable energy was presented by the Environmental Protection Agency [26] in the report titled Assessing the Multiple Benefits of Clean Energy: A Resource for States. To facilitate the evaluation of clean energy policies, the study provides one of the first complex definitions of the multiple benefits of clean energy—"positive effects on the energy system, the environment, and the economy", which again discussed clean energy generally and attempted to cover the field comprehensively with an analytical framework, describing the whole process that can be used by policymakers to evaluate those benefits during the development and implementation of clean energy policies and programs, always focusing only on one area (=specifying one field, one effect). This document clearly shows indirect benefits resulting from the RES implementation—technical, environmental, and economic (Table 1).

This document was extended and completed by presenting a complex detailed approach to evaluate multiple benefits of energy efficiency and renewable energy in [7]. This updated approach aims to be the main useful tool to evaluate the multiple benefits mainly for the policymakers, emphasizing that the multiple benefits are still not widely used in the decision-making process.

The study [7], therefore, categorizes different types of multiple benefits. The main contribution of this study lies in providing a complex methodology, the way how to assess the multiple benefits depending on the goal and metrics the policymakers aim to reach (GHG decrease, employment increase). All benefits are divided into three groups; the benefits for the electricity system, environment and economic welfare (Table 1).

We agree with the majority of the effects presented in this study [7]. Some of these effects were proved and mapped so far, while not all the effects are directly stated. Therefore, we present detailed literature analysis to bring a perspective that is in line with new trends. In our review, we therefore add the overview of all effects and aspects of renewable energy development and show the relations between them.

Table 1. Structure of "multiple benefits" of clean energy reproduced from U.S. Environmental Protection Agency (EPA) [7].

Electricity System	Primary benefits	Lowered costs of electricity, wholesale electricity decrease, decreased costs of expanding new sources
	Secondary benefits	Lowered ancillary service costs, lower wholesale market clearing prices, increased power quality, improved fuel diversity, a decreased risk for investors in the energy field
Environment Benefits (Emissions and Health)		Decrease in the production of air pollutants and greenhouse gases
Economic Benefits		Direct and indirect—household and business costs, program administrative costs, construction and operational costs, waste heat savings employment increase, public health improvement, gross state product increase, and citizens' income.

Following the structure of [7], electricity system benefits, which can be called also supply-related, are divided into primary and secondary. They are closely connected to the economic effects, e.g., wholesale electricity decrease may result in lowered household and business costs [49–53]. In our opinion–the decrease in air pollutants production is in direct relationship with public health improvement [15,54–56], which is in the above structure assessed as an economic effect. The study [5] further lacks the other side and indirect effects, very often mentioned in the RES development, such as energy access, energy safety, etc. While the study provides a methodology for evaluating the multiple benefits, it does not provide the data on the quantification of individual benefits. It must also be noted that the report [7] focuses only on benefits, not aiming at covering comprehensively all impacts. It is not entirely clear if the effects are beneficial for society or individuals. As presented further in our paper, a purely positive direction of the above impacts can be at least disputable.

The International Renewable Energy Agency (IRENA), as a key player in the field of analysis of the RES impacts, offers comprehensive studies showing positive impacts of renewables on climate change, finance and investment, innovation, or jobs [57–60]. The study [6] also provides the first complex evaluation of economic—non-energy—impacts of renewable energy and contributes to this discussion with the first global quantification of the macroeconomic impact of doubling the global share of renewables in the energy mix by 2030 [6] on economic growth, welfare, employment, and international trade. At the same time, a simple quantification of MI RES is provided, estimating positive impacts on

- economic (macroeconomic effects)—GDP, welfare, employment, trade balance
- distributional effects—impacts between energy consumers and customers, regional distribution
- technical (energy system-related effects)—additional generation and balancing costs, additional grid and transaction costs, externalities,
- additional effects—risk reduction, others

This approach shows that GDP, welfare, employment, and other indicators, which are easily quantifiable, are positively correlated with the RES development, again distinguished to economic and technical ones. This approach lacks environmental benefits, either direct (air pollution decrease) or indirect (health benefits), and the benefits resulting from electricity price decrease (e.g., energy poverty alleviation) or distributed energy increase (e.g., energy security).

Additionally, several other approaches have also been used to understand and describe wider relationships among energy system development and societal choices. A type of model called IAM (Integrated Assessment Model) is widely used and explored [61–63]. Generally speaking, this type of model combines the knowledge and relationships from different perspectives to describe human society and its interaction with other technical and economic systems, which may differ in the purpose and implementation of a specific IAM.

IAM models dealing with sustainable development comprise the models from different areas. They are divided into two types of models—simple and complex [61,64,65]. Simple IAM models generally assess the benefits and costs of limiting global warming. They often adjust the "social cost of carbon", by quantifying monetary costs and benefits of every single additional ton of CO_2 [63,66,67]. More complex IAM models integrate several models representing different inputs into the whole system. These models combine modules expressing the behavior of interconnected (even seemingly unrelated and isolated) systems as follows:

- Energy production technologies, development and exploitation
- Demand for energy models
- Energy exploitation choices—transformation of energy; transport; heating; battery systems, etc.
- Land exploitation choices—especially in agriculture, biomass production
- Climate models
- Economical models—markets, models of global economy
- Models of socioeconomic behavior—GDP modeling, population development
- Energy policies implementation

IAM models provide a simplified, yet very robust, rigorous and numerically intensive processing of the overall situation, trying to cover all consequences. While the demand for energy increases, the economic module registers the energy price changes, which may lead to the change in behavior of some consumers. Some IAM models also include the modelling of impacts of natural sources management and air pollution, but, unfortunately, often lacks specific results (mostly GDP and employment) [61,68].

On the other hand, these models try to provide a complex view on the functioning of the whole system, respecting all the relations among technical, environmental, and socioeconomic aspects of sustainable development, which provide quite a good step to taxonomize and assess our multiple impacts [69–76]. These approaches, while focusing on proving RES impact on quantifiable variables (GHG, mortality, subsidies) easily, do not often include other benefits (employment) and often miss the potential co-benefits or efforts and economic benefits, and also other MI are rarely included. Our approach can help these models to fill in the gap and better interpret the results of the models such as Multiple Criteria Decision Analysis and Integrated Assessment Models (MCDA, IAM) and others.

Even though there are commonalities in the above approaches, we can see that both the MI definition and taxonomy are relatively ambiguous. The distinction between MI RES and MI EE is sometimes vague. Also, it is not always clear what the origin of the impact is and what the effect is. For example, the RES development in electricity production is connected with the market price decrease that may result in a wholesale price decrease, but not necessarily, e.g., although Pena [20] claims that the RES production increase negatively influences the wholesale electricity prices in all analyzed countries, Batalla [77] admits that the increased renewable production is linked to an increased amount of ancillary services, which can lead to the increase in the wholesale price, which can or cannot contribute to the general welfare. Similarly, the economic growth, measured by GDP, is affected by a plenty of factors, and it may be difficult to specify the exact contribution of the RES implementation to the well-being of people. Even in the technical field of renewable energy sources implementation, causality and effects are not entirely clearly distinguished.

As we mentioned above, it can be very challenging to prove which direct effects result in which Multiple Impacts. These effects can be assessed from different perspectives, on the micro and macro level, on the national, regional and individual level. We provide the following analysis and overview of the complex interconnected effects resulting from the RES implementation, presented and summarized in Figure 1:

(1) We assume that direct Technical effects are as follows:
   - Increased RES share results in the decrease in fossil and traditional sources share. [1,6]. This can lead, among others, to emission savings or energy security and energy independence increase [1,13].
   - Increased distributed energy production decreases the amount of electricity transmitted over long distances, which results in the decrease of costs of losses in a transmission grid (TG) and distribution grid (DG) [8,23,78]. It can positively influence the wholesale electricity price decrease [1,79], which helps to improve energy access. [1,13].
   - Distributed energy production provides better energy supply, and thus improves power quality, in terms of ensuring the electricity supply not only in remote places or developing countries [13,80–82].
   - Distributed energy production improves fuel diversity, and thus energy security [1,8,26].
   - On the other hand, the intermittent character of renewables put significant demand on the grid balancing [83,84], which requires more flexible ancillary services for the grid management, very often provided by gas stations or battery services [29,85–87]. These sources can be capital- intensive, which can increase the wholesale price, thus being in contrast with point 1 [52,88,89]. Also, a quick-start fossil fuel production can result in real GHG emission growth [45]. Therefore, these effects can be positive or negative, depending on the perspective of the stakeholder.
   - The intermittent character of RES can also lead to the increase of risk and security issues, due to the uncertainty, from technical and also economical perspective, which leads to the use of more complex methods for design and optimization of the grid management and development [90,91].

(2) We assume that direct Economic effects are as follows:
   - Different costs on expanding new sources and low RES maintenance costs is connected with a merit order effect, which lowers the market electricity price [20,89,92,93]. On one hand, this can lead to uncertainty in the investment field for traditional/conventional sources, but on the other hand, it leads to the price decrease for businesses and households [50,94]. Cheaper energy can improve energy access, can decrease energy poverty and improve education in developing countries through better energy access [82,95,96].
   - On the other hand, increased ancillary services provided by cost-intensive sources can lead to the wholesale price growth, as discussed before.

(3) We assume that the Social effects include mainly the sector of renewables development, which results in employment and productivity growth, which can be observed by the GDP growth or public budget increase.

(4) We assume, that direct Environmental effects are as follows:
   - Decreased fossil share helps to mitigate GHG emissions and air pollutants, and thus it contributes to emissions savings. These effects are in the direct link to air quality improvement and public health improvement. [7,26,42,97].
   - On the other hand, we should remind the previous discussion that renewable development can be developed hand in hand with the increased backup sources, which can be linked to the total emission increase [45].

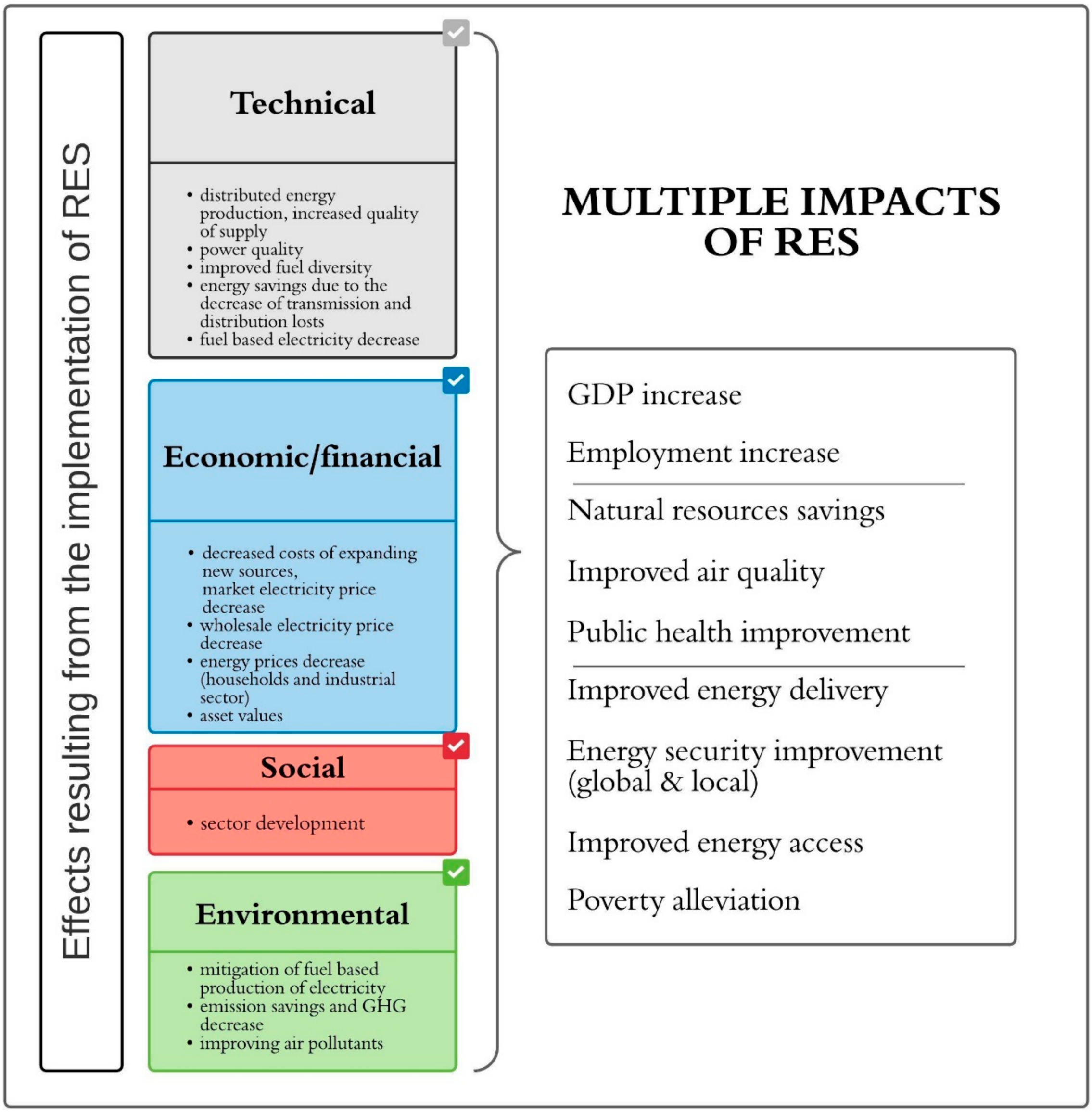

Figure 1. Our approach to multiple impacts.

We can conclude that the renewable energy development results in a wide and complex list of effects. The results are summarized in the left part of Figure 1. All these effects were described and summarized based on an in-depth literature review discussed in the above-mentioned text and are typically assessed in the evaluation of the RES development. These effects then jointly and interconnectedly contribute to the overall, ultimate multiple impacts, described on the right side of Figure 1. Both the individual effects and impacts can influence either individuals or society as a whole.

The main idea of our approach is as follows: the left side of Figure 1 present the direct effects resulting from the implementation of RES, which are properly and comprehensively mapped in literature [1,7,26] and used in political discussions and decisions, very often evaluated and used as arguments for further RES development.

The right side of Figure 1 presents the effects called Multiple Impacts of RES (MI RES). These existing impacts (GDP growth, employment growth, air quality improvement) are mapped and confirmed by several studies, but not always in connection with RES—it can be very challenging to prove, e.g., that the RES implementation has a direct impact on the GDP growth. Therefore, the argument of multiple impacts, as we define and present, is not often used in political debates in the RES development. This paper aims to show that these effects exist and that renewables contribute to them by an overview of studies assessing these impacts. Our goal is not to enumerate the exact contribution of RES in individual areas, but rather to prove the existence of MI RES, to assess them and quantify the impacts on the society benefits given by its development. These arguments can thus support the political debate in the subsequent development of RES to fulfill the targets mentioned in the first part of this paper.

Following the above-mentioned discussion, we define the multiple Impacts and effects of renewable energy (MI RES) as all benefits which are private and general in addition to the direct individual financial benefits and costs. We, therefore, extend the concept of multiple impacts to entail both effects and impacts, which, as we believe, better shows the nature and causality of the RES development. In the following text, we provide a literature overview and discussion, which helps to better understanding of the relationship between the RES development, the effects, and the ultimate multiple impacts of RES. To do this, we use the structure from Figure 1.

5. Review of Multiple Impacts

This section is focused on the assessment of the multiple impacts RES. We follow the structure and definition of MI presented in the previous section. We divide MI RES into three groups, covering all effects comprehensively; economic MI RES (GDP, employment), environmental MI RES (nature resources savings, air quality, public health), Energy security MI RES (energy access and delivery, energy poverty alleviation). Such a structure helps to clarify the interconnection between individual multiple impacts, and also various effects affecting the impacts. By reviewing the effects and multiple impacts, we strive for understanding the mutual relations among all involved factors.

5.1. Economic MI RES

The fact that the development of RES helps to increase employment was one of the most developed fields of the MI RES research. Moreno [98] claims that the RES development significantly positively influences an employment growth, which can compensate for the employment decrease in the mining industries. In other words, renewables are the source of significant job creation, even in comparison with traditional fossil-fuels electricity production [99–103]. Renewable energy creates more jobs in construction and installation rather than in the operation and maintenance phase, due to the low requirements of RES on operation [63]. It should be mentioned that employment contribution can be measured by jobs calculated per MW of the installed capacity, or kWh of the produced energy. In case the studies present the second approach, one should keep in mind that renewable sources are favored due to the low-capacity factor (they produce less energy per MW of the installed capacity than traditional sources).

Several studies prove the increase of level and rate of development of "green jobs". Dvořák et al. [104] analyzed data for the period 2008–2013 in the Czech Republic and compared it to the same type of data from other members of European Union, focusing on Germany as a leader in renewables. Although the Czech Republic managed to achieve a significant number of RES jobs (more than 20,000 employees in 2010), its future job development could not be reached without further financial incentives. Dvořák et al. [104] also realized, that compare to photovoltaic (PVE) sector, find that biomass and waste processing provide the highest employment rate per MWh, which can help with employment in rural areas. Similarly, Slattery, Lantz, and Johnson [105] estimated the economic and employment impacts from almost 2 GW of wind power development in four regions in west Texas and during the construction, which lasted four years, approximately 4100 full-time equivalents (FTE) jobs were created.

Other RES have been found to positively contribute to employment as well. Geothermal power generation can benefit to employment, Hienuki [101] estimates the contribution as 0.89 person-years per GWh for whole life cycle (in Japan), assessed in all phases which include research of the proper location, construction, operation, and disposal. Hienuki also compares differences between the job creation of geothermal, wind and PV power production and claims that geothermal power generation contributes to long-term jobs more than wind or PV, mainly due to the intensive investment phase.

Markandya et al. [99] present a more global analysis. They analyzed the change in the European electricity and gas supply sector structure in 1995–2009, and prove that this change had a net positive impact on employment in the EU total (+530,000 jobs), and mainly in 21 out of its Member States. Similarly, Lehr et al. [102] assume that RES for electricity and heat generating in Germany brings the local benefits, developing three scenarios, differing premises for fossil fuel price development, installations on family houses, and international trade evolution, while almost all of the scenarios proves the benefits for the employment. In the medium scenario, the net employment effect would achieve around 150 thousand in 2030.

The impact on employment is often connected to the broader assessment of economic impacts, mostly measured by GDP. Arabatzis and Myronidis [106] assess that the development of small hydropower stations (in Greece) positively contributes to local and regional development, mainly to the jobs creation and incomes of the population of the area with a very low environmental impact. Silalertruksa et al. [100] analyze the impacts of biofuels production on socio-economic development in Thailand and find that the main contribution of bioethanol production is the contribution to employment (around 300,000 person-years in 2022, which is about 17–20 and 10 times more workers than gasoline and diesel, related to an energy content) and GDP increase in the level of 150 million $. Also, Herreras Martínez et al. [107] assess GDP and employment growth in the field of bioethanol production in Northeast Brazil, differing three scenarios, but all proving employment and GDP benefits. Confirming the positive impact of RES on employment and economics, Blazejczak et al., 2014 [14] reveal a positive effect on economic growth in Germany, also with employment effects, which are not so significant, but also positive. Their size depends significantly on labor market conditions.

Additionally, several studies focus solely on the relations between RES development and economic impacts. Apergis and Payne [108] examined the relationship between renewable energy consumption and GDP for twenty Organisation for Economic Co-operation and Development (OECD) countries over the period 1985–2005. They found bidirectional causality between RES consumption and economic growth. This is confirmed by Andini et al. [109] who suggest that both the investment and operational phases of the implementation of renewable projects contribute to the economy; the benefits of the investment phase are temporary but permanent for the operational phase. Narayan and Doytch [110] show the opposite relationship i.e., economic growth has a positive and significant effect on the consumption of RES just for the low and lower middle income countries.

Some studies go even deeper in enumerating the GDP benefits of RES implementation. According to Fang [111], a 1% increase in renewable energy in China increases real GDP by 0.12%; GDP per capita by 0.16%; per capita annual income of rural households by 0.44% and per capita annual income of urban households by 0.368%. Similar numbers are provided by Inglesi-Lotz [112] who, by analysis of 34 OECD countries (1990–2010), indicates that a 1% increase in renewable energy consumption will increase GDP by 0.11% and GDP per capita by 0.1%, while a 1% increase of the share of renewable energy to the energy mix of the countries will increase GDP by 0.089% and GDP per capita by 0.090%. These results are, however, in contrast with Adams et al. [113] who analyzed 30 sub-Saharan African (SSA) countries in 1980–2012 and found that a 10% increase in renewable energy consumption was associated with an increase in economic growth by 0.27%, while a 10% increase in non-renewable energy consumption lead to an increase in growth by 2.11% ceteris paribus, which the authors explain as an effect of developing countries, because only recently the analyzed countries in the region had started investing in the RES. Similarly, IRENA [6]; provides estimates of economic impacts; quantifying the macroeconomic impact of doubling the global share of renewables in the energy mix by 2030—GDP growth 1.1%, 24 million jobs in renewables, 3% growth of welfare and opportunities of new markets.

The studies therefore clearly confirm that RES expansion can be achieved without compromising growth or employment.

5.2. Environmental and Health MI RES

Apart from economic impacts, the RES development is positively associated with environmental and health benefits. Most commonly, the RES development is connected to CO_2 decrease, which is, in turn, linked to positive economic impacts. According to Belaïd and Zrelli [36], higher renewable energy consumption significantly increases GDP and decreases CO_2. The study has also confirmed the long-term relationship between non-renewable electricity consumption and CO_2 emissions. These results are consistent with the study [35], which assesses the determinants of CO_2 emissions on data from 1980 to 2011 for all OECD countries and clearly prove that CO_2 emissions are increased by non-renewable energy consumption and decreased by renewable consumption. Yao, Zhang, and Zhang [30] claim that a 10% boost in the consumption of RES rate can lead to a 1.6% reduction in carbon emission although the effect depends on share of nuclear energy and RES promotion (both have positive effects).

On the other hand, due to the intermittency character of RES, a higher level and amount of backup energy is required, mainly from quick-start fossil sources. Back-up sources and their number of start-ups and switch-offs can increase, Blondeau [114] show that start-up and fast transient phases of backup sources historically contributed to less than 5% of the produced energy. At present, this share has increased up to 20%. This leads to an average increase of NO_x emissions in the range of 30–80%, and the range of 2–4% of CO_2. Therefore, the expected decrease of CO_2 emissions brought about by the RES development is lower due to the lower sensitivity to transient phases. It means that the CO_2 decrease is disputable. Unlike the CO_2 emissions, the link between RES development and the general decrease of air pollution may not be fully straightforward. Nevertheless, the studies show that renewable energy is generally positively correlated with GHG decrease.

There also seems to be a clear link between CO_2 decrease and related public health benefits [15,115]. Studies of the health effects typically focus on the concentration, GHG, and PM (particulate matter) analyses which deal with a group of significant health impacts including increased frequency of hospital admissions and increased risk of mortality [15]. Partridge and Gamkhar [54] present a methodology for estimating the health benefits from RE electricity generation and quantify some of the positive health impacts of decommissioning of coal-fired generation and supplementing the supply with wind or small hydro in China. Their results confirm that renewable energy is directly connected with improving public health.

The level of health and environmental benefits brought by the RES development depends on the location. The modeling shows that renewable energy and energy-saving projects deliver annual benefits of up to US$ 210 million across six locations in the USA [56]. Similarly, McCubbin and Sovacool [97] calculate the environmental (and economic) benefits of wind energy derived in two locations: the 580 MW wind farm at Altamont Pass and the 22 MW wind farm in Sawtooth, both in the US. The authors [97] estimate that between 2012–2031, the turbines at Altamont Pass will avoid USD 560 million to USD 4.38 billion in human health and other externalities. The turbines at Sawtooth would then avoid USD 18 million to USD 104 million.

Similarly, the report by the United Nations Environment Program [16] shows that health damage from air pollution reached over 4% of GDP in the 15 largest CO_2 emitters in 2010, and health benefits or air pollution and GHG decrease reached US$ 73 per ton of CO_2 decreased.

Conclusively, the development of RES clearly brings environmental benefits, contributes to health improvement and development [31–33,37,42,71,116]. The level of these impacts depends mainly on the type of RES, location, energy mix of the individual country, and its potential for long-term health service cost reductions.

5.3. Energy Security-Related MI RES

The conclusions about the impact of RES development on wholesale electricity prices have not been unanimous so far. The wholesale electricity market price tends to be decreasing with the development of RES [88,93,117,118]. However, the increased intermittent production brings about higher requirements on the grid balancing [3,87]. This problem occurs in both long-term (i.e., how to ensure electricity supply in the winter months during which the conditions for RES are generally worse) and short-term (i.e., seconds and minutes to balance the grid due to the technical attributes of intermittent sources). These challenges can be solved, e.g., by energy storage solutions and quick-start fossil sources [88]. However, both of them require additional investments, which may, in turn, increase the non-energy part of household total electricity prices. Peña and Rodríguez [20] observed such an effect in most of the analyzed countries.

However, in contrast to the conclusions above, other studies show that the higher share of renewable energy is not necessarily associated with higher household electricity prices. Iimura and Cross [52] analyzed seven OECD countries between 1991–2014 and found that the share of RES was not statistically significantly related to the total electricity household price. Even oppositely, Kolb et al. [92] show that in Germany, renewable energy sources reduced the wholesale electricity prices by 2.89 ct/kWh in 2014 up to 8.89 ct/kWh in 2017. In general, we assume that the positive effects on the wholesale price of electricity prevail, but the effect on the total price is uncertain.

The development of RES also contributes to alleviating energy poverty by providing accessible and affordable energy. For instance, Khanna et al. [96] assessed the effects of different types of small RES installations, ranging from a stand-alone 0.1 kW system for a single household to a large microgrid (up to 100 kW) for the whole village. The RES installations included solar, wind, or a hybrid with a diesel and a battery back-up. Thanks to the low levelized costs of energy of these systems, the share of the electricity bill for the participating households on their total income remained low, while providing the access to basic individual and commercial energy services.

These results are in line with [82,119], both analyzing the situation in the developing countries by assessing the contribution of RES energy to improve high income inequality. The studies found that in all the assessed 174 countries, RES contributed to closing the gap between high and low-income groups.

The contribution of the RES development following the household income models are presented in [114] that analyses the dependency between the increasing share of RES and both the income of households and their risk of poverty in 15 EU countries during 2005–2015. Several important findings result from this study; first, the income of households is positively, but differently, correlated with different RES technologies—hydro and PV sources are favored. Second, the other result was the negative correlation of a solar PV deployment with household income. Thirdly, the installed capacity of wind and hydropower, and the whole RES production have reduced the risk of poverty for some households, but have increased the risk for others. Unfortunately, this study does not prove that a solar PV reduces the risk of poverty.

Renewables are one of the main pillars contributing to the European security of supply, although claiming that flexible capacity provided by fossil fuels increases the demand for imported fuels [79,92,120–122]. Also, the contribution to poverty alleviation was proved.

6. Discussion

The assessment of RES impacts is crucial to make optimal energy and policy choices for future sustainable development. Very often, these impacts are measured by direct assessment of GHG decrease or economic contribution, typically evaluated by comparing direct costs and benefits. This paper shows that a complex view on the RES contribution is necessary. However, mainly due to the complexity of assessing MI RES, these effects have not been so far fully incorporated in the energy policy design [7,8,121,123,124].

We show that renewable energy development results in several direct effects, which is presented and summarized in Figure 1 (left side). We provide the analysis of the effects by deep overview of literature and we divide them into four areas. Then we synthetize the results and relations between different effects and conclude that these effects clearly contribute to the impacts, presented on the right side of Figure 1. These impacts are called Multiple Impacts of RES. The reason why we provide an overview of MI RES together with their assessment is that not all of them have been so far discussed in the context with the RES development.

We proved that the RES implementation contributes to the distributed energy production development. Increased distributed energy offer many effects, e.g., distributed energy implies higher requirements on grid balancing, very often requiring new expensive backup sources, fuel quick start sources, or battery systems [77,87,125]. This can increase final households' costs due to the increase of a non-energy part of a final household/business electricity price [52,92].

On the other hand, low investment costs on renewables result in different costs on expanding new sources and a wholesale electricity price decrease. Due to the merit order effect, the electricity market price decreases, which results in many effects [52,92,93,96,118]. One of them is possible decrease in a final household and business costs price, which helps to improve the energy access and industrial sector development, and it can, moreover, contribute to the poverty alleviation. This effect was not proved so clearly due to possible increase in a non-energy part of final electricity price, but final decrease in costs is expected. The final effect of the decrease in final electricity price is at least disputable, although many studies tend to prove the final price decrease. Also, the benefits for public budgets are expected due to the locality of the investments.

Furthermore, it is very important to mention that low market electricity price can result in high uncertainty in the investor field because the market price can get, in long perspective, under operational costs of traditional sources [20,88,92,117]. This fact leads to market distortions, which brings even more uncertainty to the energy field.

Distributed renewable energy production provides a cheap solution to ensure energy supply and enables enhancing energy delivery and poverty alleviation [82,96,126]. Due to lowering energy dependency and diversifying a fuel portfolio, the RES implementation improves energy security, both local and global, which also contributes to the power quality increase.

Fossil fuel share results in possible savings of GHG, CO_2, and air pollutants. This effect, if positive, is in a direct relation with the improvement of air quality and public health [48,56,97], which can be quantified, e.g., by cost-saving in the healthcare budgets. Fossil fuel share decrease and the RES development also results in improved fuel diversity, which contributes to the local energy security and natural resources savings. The RES sector development evidently positively influences employment, which was proven in [14,55,98,100,103–107,127,128]. To conclude, renewables contribute to benefits in health, environmental, and economic welfare.

All impacts presented in Figure 1 (right side) were classified as multiple impacts of RES (MI RES), which are partly defined, analyzed, and taxonomized in several studies. These MI RES are the effects that are directly related to the RES increase and should be considered as an inseparable part of the decision-making process and all the discussions related to the RES implementation. MI RES result in benefits for both society and individuals, as well.

Nevertheless, our approach still lacks a detailed description of the complexity of all relationships between individual factors and the way how they influence another RES development. We should emphasize that the multiple impacts (MI) can play an important role in the investment decisions [95], especially those made by households. Korcaj et al. [129] surveyed 200 households about their intention to purchase photovoltaic panels (PV) and modeled the intention as a function of attitudes to non-financial benefits showing that households strongly (statistically significantly) consider these ecological and social factors—most concerned factors were individual autarky and global environmental concerns. Salm et al. [130] analyzed the risk-return expectations of the potential German community of investors investing in renewable energy. They found the return of investment was a relevant factor, but the community aspect of renewables and sustainable development was equally important to the households. Environmental benefits were also found to have a significant impact on the decision-making in [131,132]. The authors show that unlike general perception in business investors, the relation between RES share and non-financial drivers is also strong in this field. Hand in hand with (and overlapping) the multiple impacts, the investors' attitude to the renewable technologies may also be a crucial factor. The studies show that investors (mainly households) consider not only financial benefits but also others. However, the complex view on Multiple Impacts consideration in the investment decision-making process has been inadequately addressed. One of the most important issues for further research is how important the role of the Multiple Impacts in the investment decision-making of households and other "small investors" is, and how the phenomenon of multiple impacts could be helpful in reaching particular environmental policy goals [36].

7. Conclusions and Policy Implications

The purpose of the paper is to fill in several gaps in the research of MI RES by overviewing all the effects resulting from the RES development and determining which are direct and which are indirect. The indirect effects are called Multiple Impacts and we provide the overview of their used methodologies by systemizing their approaches and concepts. We found the key challenges to identify, quantify, and integrate MI RES with respect to improving a green policy implementation. In our paper, we show that renewable energy in the power sector influences many aspects of both economy and society and it is not often straightforwardly showed what the actual effects and what the sources of these effects are. The paper, therefore, proposes a new methodological framework for the definition of multiple impacts that can be applied in systematic mapping of their interactions, and their consistent integration.

Based on a thorough literature review, we have shown that renewable energy positively contributes to economic welfare. We assess the growth of economic welfare by employment and GDP growth, respecting all the pitfalls of this approach. We understand that GDP and employment growth are affected by a plenty of factors, thus this part of our paper contributes to the discussion by providing the overview of case studies presenting the positive financial MI RES. These studies differ on the results of the evaluation of the rate of the benefit contribution by enumerating these benefits in a different way. Some of the studies compare the GDP, employment, and welfare benefits with the required investments, trying to quantify the ratio of investment per unit of economic welfare. However, the positive MI RES in the economic field is evident. More difficult to decide is whether these benefits also contribute to well-being of people by improving energy access, and thus alleviating poverty.

We can see that RES contributes to the mitigation of the fuel-based production of electricity and decreases emissions of CO_2, GHG emissions and air pollutants. These effects directly contribute to improved air quality, natural resource savings, and public health improvement, which can be compared to the costs, typically invested to cover these effects. Although the emission production is directly positively correlated with the renewables development, some studies show that the benefit rate can be impacted by the amount and by the type of backup sources—if the backup sources necessary for a grid management are primarily fossil fuel-based, the total sum of emission savings can be negative. This can be solved, e.g., by using batteries and other storage systems to overcome the intermittency of RES.

It can also be concluded that renewable energy contributes to the increase in distributed energy, power quality and fuel diversity and energy savings due to the decrease in transmitted energy over long distances. Distributed energy also contributes to improving energy access, energy security and energy delivery. This may result, which is not proven but expected, in geographical energy independence—a topic that starts to be more and more important.

To be concluded, firstly, all these impacts, as elaborated, can contribute to the effectiveness of policies of energy field development, from systemic societal perspective to cover all aspects of RES development. Only full picture of all positive and negative multiple impacts can contribute to the proper development of the energy sector, both locally and globally.

Secondly, elaboration and evaluation of all Multiple impacts of RES should serve to the proper understanding how to promote further RES development, from government perspective and also, from individual investors' perspective. These impacts for individuals and society, directly linked to the willingness to purchase small RES sources, are key drivers that should be explored and described. MI RES play potentially a significant role in "small" investors' decision making and, therefore, fully understanding how the MI RES are incorporated in the investment decision process will be the next step to designing better and more effective policy for RES development.

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