Article

Possibility of Hydropower Development: A Simple-to-Use Index

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Abstract: A standardized range system based on carefully selected multi-criteria is proposed in
this work to assess the feasibility of hydropower implementation. A thought process has been
developed as a simple-to-use and easy-to-understand methodology. Today, due to the broad concern
for the natural environment, the use of renewable energy sources has become globally popular.
Subsequently, such solutions as the application of renewable energy for electricity generation are
often considered the most environmentally friendly installations. Unfortunately, no methodology to
assess the possibility of hydropower plant realization in either scientific or industry literature has been
put forward, and this constitutes a blatant failure. The proposed range system has been designed
to use selected information (head, available flow, fish migration, hydrotechnical infrastructure,
protected areas, environmental flow, status of surface water body), which is available through a
variety of sources that are easy to obtain. From analyzing the advantages and disadvantages of this
research method, it was recognized that it is worth propagating and recommending for the practical
estimation of the hydropower potential. The author believes that the novel contribution of the paper,
which is the innovative range system, will be accepted for common use.

Keywords: hydropower potential; renewable sources of energy; hydropower plant; sustainable
development; possibility assessment

1. Introduction

The obligation for a given percentage share of energy production to come from RES
has been stipulated in many legal regulations, including those for the EU member states.
Thus, their pro-ecological nature has been confirmed by the law.

The proposed range system has been designed to use selected information available
from a variety of sources. Information on the parameters (including the protected areas,
status of a river, fish migration, and hydrotechnical infrastructure) is necessary to evaluate
the main barriers to SHPP realization. This information is easy to find in many web portals,
maps, or commonly available data shared by water management organizations. Although
much of this information is available in existing sources, some might require estimation.
The A and EF are based on water gauge observations and need to be calculated according
to the obligatory methodology in analyzed countries. The existing head of the dam could
be obtained from the available sources (tables, published information, etc.), but the possible
head needs to be checked in the field. It is important to realize that the proposed range
standardized system provides only a general broad assessment to be used to evaluate a
section of rivers for potential SHPP.

Based on the practical experience of the author, supported by a review of completed
and published studies [1–6], it can be concluded that there are deficiencies and inaccuracies
in the commonly available studies, both methodical and scientific. Indication of a real
possibility of implementing hydropower plants, which takes into account the aspects of
care of the environment, i.e., in accordance with the principle of sustainable development,
while completely omitting these barriers in the mathematical analysis of the hydropower
potential, is specific to the studies in the field of hydropower engineering. At present, every

human interference with the natural environment related to economic development must be carried out in respect of environmental components and the search for compromise solutions [7–10].

The presented index system for the assessment of sustainable SHPP realization, called HAFIPES, is based on key procedures that may be different in different countries, but the main course of the analysis seems to be rather universal. Of importance is the fact that all installations of SHPP should be compatible with sustainable development and good protection of the natural environment. The results make it possible to select the most favorable places for the realization of SHPP. A quantitative assessment of hydropower potential (e.g., technical or economic potential) could be done on a case-by-case basis in the next step. The proposed HAFIPES system constitutes a range-standardized system that brings out the initial information without having to calculate the hydropower potential in MWh. The results of the "HAFIPES index ranges for the probability of SHPP implementation categories" have no units.

There has been an attempt at the assimilation of scientific thoughts with experts' experiences in the process of evaluating the possibility of hydropower plant implementation of a river. No similar method has yet been put forward in science or practical guides. The main intention of the author was to use the proposed system as a screening tool, which has never been implemented so far. This range system has been designed to use selected information available through a variety of easy-to-get sources. Selected factors (head, available flow, fish migration, hydrotechnical infrastructure, protected areas, environmental flow, and status of SWB, which form the acronym HAFIPES), are incorporated into a relative ranking scheme that uses a combination of weights and ratings to produce a numerical value called the HAFIPES Index. The basic factors and the numerical coefficients assigned to them are highlighted; subsequently, a mathematical formula used to analyze possible results is proposed. The system has two major parts: designation of mappable units—hydropower settings and superposition of a relative rating system. Hydropower settings constitute the basis of the system and incorporate the major hydropower, environmental, and hydrotechnical factors, which could determine the feasibility of hydropower plant implementation. The presented method to determine the prospect of hydropower plant implementation, being simple, consistent, and based on real conditions, may be used universally. If frequently used, the proposed HAFIPES system could improve the quality of studies on the hydropower potential of watercourses, providing a quick and inexpensive analysis in support of individual investors making investment decisions.

2. Materials and Literature Overview

In most of the works on hydropower potential assessment, simple calculations are used to estimate the hydropower potential in different regions of the world, such as TP exclusively for China [1]. TP was also estimated numerically for Colombia; however, environmental limitations were just pointed towards but were not considered in the calculations [2]. Similar considerations covering the barriers and possibilities of SHPP implementation have been presented for Romania, but the figures of the presented numerical potential values only covered total potential [3]. For the area of Scotland, based on a review of the work of other researchers, Sample et al. [4] presented different potential values in a wide range of 217–1049 MW. In summary, the results from different authors are not directly comparable, as the methods used and key assumptions (without accounting for planning constraints, 8% discount rate assumed, 10% discount rate assumed, 5% discount rate assumed or after "technical screening") are not standardized [4].

Analyses of available scientific articles and studies show that often one type of study prevails, i.e., theoretical, technical, and mechanical ones. Such articles [11–14] most often focus on the possibility of improving the efficiency of turbine sets in hydropower power plants in order to make the most efficient use of the river flow. The vast majority of them do not even specify the disposable flow for the power plant, i.e., taking into account the need to maintain an inviolable/environmental flow [15]. The environmental studies published in

the field of hydropower engineering are frequently associated only with the analysis of the negative effects of hydropower projects in the course of their operation. However, there are no studies where analysis of potential future possibilities of hydropower development of watercourses has been carried out simultaneously with a number of aspects accompanying the abstraction of natural waters (legal procedures, energy management of technological waters, so-called "good practice", environmental impact, protection against degradation, barriers, and restrictions on implementation, etc.) [16].

As a result of the previously conducted and published research work [7], a method of numerical assessment of hydropower potential based on the actual capacity of SHPP has been refined, with a comprehensive assessment that takes into account the sustainable development of aquatic ecosystems, introducing a new aspect of the assessment. In the course of the research carried out by the Operacz so far, a new term, "effective potential", has been coined (Table 1). This term shows the actual possibilities of SHPP implementation based on sustainable development [7,17,18].

The basic and general definition of "potential" has been described in the Glossary of [19] as "the possibility of something happening, or of someone doing something in the future". Theoretical potential, technical potential, and economic potential are the terms commonly used in estimating the hydropower potential of rivers or their sections. Such a different approach to the assessment of hydropower potential, based on different assumptions and methodology of quantification, generates some discomfort in interpretation, with the results often being overestimated and inaccurate, especially when results are to be qualified under the common name of "potential".

Table 1. Examples of the definitions of RE potentials.

Author(s)	Definitions
Stangeland [20]	Realistic potential: the amount of energy that can realistically be utilized after marked barriers and other barriers such as social acceptance, environmental factors, and area conflicts have been taken into account. Realizable potential: the energy that can be realized within a given timeframe. This energy potential depends on economic conditions as well as global market production capacity.
Hoogwijk and Graus [21]	Market potential: the market potential is the total amount of RE that can be implemented in the market, taking into account the demand for energy, the competing technologies, the costs and subsidies of RES, and the barriers. As opportunities are also included, the market potential may in theory be larger than the economic potential; however, the market potential is lower because of all kinds of barriers.
Krewitt et al. [22]	Deployment potential: characterizes the potential market uptake of RE technologies under pre-defined framing conditions. It depends on, e.g., the structure of the existing supply system, the development of energy demand, and energy policy targets and instruments in place. Demand potential: with the increasing competitiveness of REs, in the future, the economic potential may exceed the energy demand. In such a case, the deployment potential of RES will of course be limited by the energy demand.
Resch et al. [23]	Realizable potential: represents the maximal achievable potential assuming that all existing barriers can be overcome and all driving forces are active. Thus, general parameters, such as market growth rates and planning constraints, are taken into account. It is important to mention that this potential term must be seen in a dynamic context, i.e., the realizable potential has to refer to a certain year. Mid-term potential: the mid-term potential is equal to the realizable potential for the year 2020.
Operacz [7]	Effective potential: the actual river potential that may be achieved in a short time under conditions of the existing legal regulations. It does not take into account the economic analyses (individual and energy market). It is determined based on the real current application of procedures and significant limitations (the environmental situation as well as existing and manageable hydrotechnical infrastructure).

A brief overview of the literature shows that this term is usually not universally accepted. Most authors come up with their own definitions that are mostly not well

explained, sometimes seemingly simple but difficult to understand and to generalize [7]. Many authors use interchangeably the names and definitions of RE potentials, leading to many misunderstandings and mistakes. Table 1 presents intuitively similar definitions of hydropower potential; however, many of them existing in science provide no clarity on assessed values, and their authors often do not put forward any clear methods for quantifying the numerical values of the proposed hydropower potentials.

The EP term proposed previously by Operacz [7] includes bureaucratic, environmental impact as well as any other additional procedural regulations. The author proposed this term in order to make it possible to estimate the production of energy from a given river using the method closest to the actual possibilities of execution of new SHPPs in line with the sustainable development goals (with respect to the environment), without economical calculations (actual energy market, price, cost, and individual financial conditions of investor) [7] (Figure 1). This is very important to maintain the minimum environmental flow as a factor of significant environmental impact. Environmental flow is the volume of water that cannot be used for energy generation purposes and mainly affects the real "effective potential" [7]. Limited by the necessity of leaving the idle flow in the watercourse, the number of days of operation of a hydropower plant causes lower annual production. Not including this obligation is the critical error and results in overoptimistic data. Unfortunately, environmental flows remain overlooked in run-of-river hydropower plants [24]. Environmental flows are crucial for the sustainable expansion of run-of-river hydropower [25].
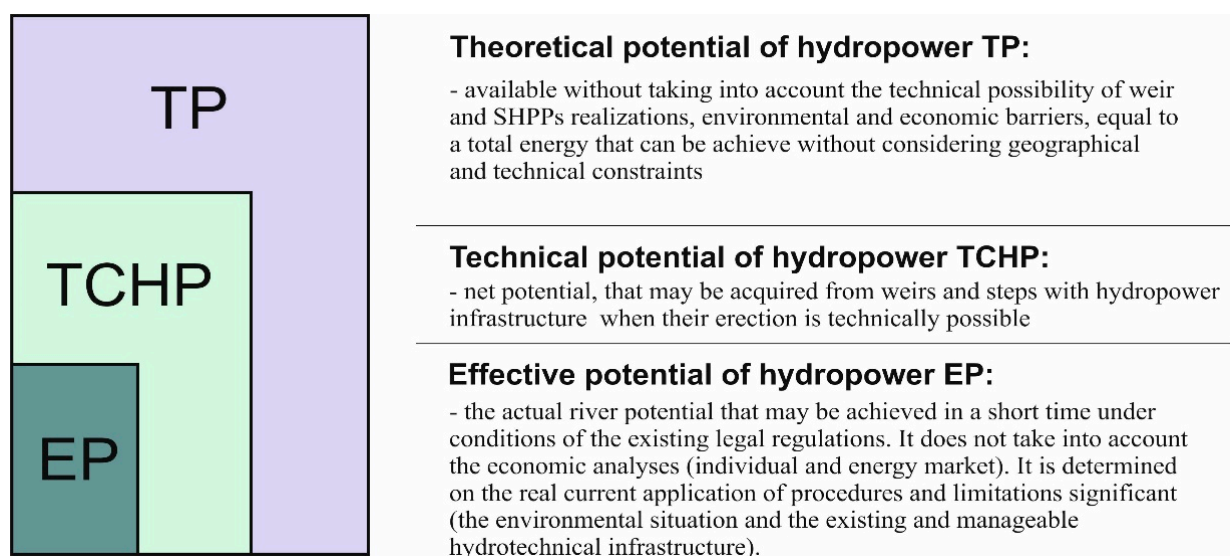

Theoretical potential of hydropower TP:
- available without taking into account the technical possibility of weir and SHPPs realizations, environmental and economic barriers, equal to a total energy that can be achieve without considering geographical and technical constraints

Technical potential of hydropower TCHP:
- net potential, that may be acquired from weirs and steps with hydropower infrastructure when their erection is technically possible

Effective potential of hydropower EP:
- the actual river potential that may be achieved in a short time under conditions of the existing legal regulations. It does not take into account the economic analyses (individual and energy market). It is determined on the real current application of procedures and limitations significant (the environmental situation and the existing and manageable hydrotechnical infrastructure).

Figure 1. Terminology and basic methodology of potentials assessment [7] modified.

In the proposed system, an attempt was made to assimilate the thought processes of scientists with practice experts when evaluating the possibility of hydropower plant implementation of any area river. From this thought process, an attempt has been made to develop a simple-to-use and easy-to-understand methodology. It is important to note that the main intention of the author was to use it as a screening tool, not to replace the need for professional expertise and fieldwork required to assess the hydropower potential (e.g., technical, economic) in specific rivers' sections.

For the decisions on the location of hydropower power plants, in Poland (as in all EU member states), there is an obligation to carry out an assessment of the impact of these facilities in the natural environment, as such projects are classified as potentially significantly affecting the environment [26,27]. A very important element of such an assessment is the expected impact of the planned (often existing, in the case of expansion) facility on the broad natural environment (surface waters, groundwaters, ichthyofauna, etc.). Such an assessment is drafted up by one or a group of authors in a manner consistent

with the latest knowledge and experience of the authors. However, such an assessment has a certain degree of subjectivity and covers only the impact on the environment.

A large body of literature clearly shows that there are many guides or courses on "how to build SHPP" [28–30]. In all of them, there is a common conclusion that developing a small hydropower site is not a simple task, as many aspects that have to be taken into consideration are widely described. Usually, the tasks cover the same conditions including business, engineering, financial, legal, environmental, and administration. All these aspects are necessary at different development stages, from first choosing a site until to the moment the plant goes into operation [29]. Hartmann et al. [31] noted that considerable progress has been made on the sustainability of individual hydropower projects, but this will not be sufficient to address the complex issues posed by multiple hydropower developments across a river basin or region. Sustainable development of hydropower requires system-scale planning, and management; this is known as the "next frontier" in hydropower sustainability. The authors of [31] developed a simple framework that can build and compare development scenarios in an iterative fashion, seeking balanced outcomes across multiple values. The proposed HAFIPES index is based on the presumption that the "optimal" process has the best prospects of achieving sustainability.

In practice, developing a hydro project always constitutes a challenge. Proper assessment of hydrology conditions (which impacts power generation and revenues) and hydrotechnical geology conditions (which may increase construction costs) have a huge influence. Site licenses and necessary permits are usually difficult to obtain, as this usually involves many stakeholders (ground owners, fishermen, environmental protectors, water management organizations, and others). It is important to find a compromise between conflicting rights and responsibilities with minimizing the negative impact on the environment. Environmental risks are variable and depend on the conditions of the chosen site. Omission of the assessment of environmental barriers may introduce high risks for the investment or even finally block it. For these reasons, an SHPP project possibility assessment would seem a necessary initial action.

There are no objective studies based on uniform criteria to assess the possibility of implementing SHPP. The so-called "SHPP construction concepts" function in practice, but they are very specific and made to the order of the potential investor in a manner not regulated by any legal provisions. Hence, the scope of such concepts is very diverse and based on many different criteria. International Hydropower Association (IHA) is an example of a professional company that supports hydropower development by providing guidance on international good and best practice as well as facilitating sustainability assessments [32]. The company offers the Hydropower Sustainability Assessment Protocol (HSAP) as a way to evaluate the hydropower project across more than 20 selected sustainability topics [33]. The HSAP can be used at any stage of the hydropower project's life cycle, from the earliest planning stages right through to putting it in operation.

In the opinion of the author, SHPPs are always custom-designed, site-specific, and very specific projects. There is thus a strong need to introduce a uniform system for estimating the possibility of SHPP creation. Such a system could be widely used both by individual investors (seeking an optimal location for a single SHPP) and by self-government bodies (when drawing up various studies of the hydropower potential of watercourses). Until now, there has been no similar system or any other quantification course to assess the probability of SHPPs realization. Existing literature on the subject only offers equations for quantifying hydropower potential without any initial assessment of investment probability/risk.

Based on a wide review of the existing literature on the subject, the author has selected the most often met conditions to implement SHPPs, namely environmental impact, government support (certificates, price of electricity generation or other extra payment), availability and technological limitations, hydrology (available flow), and social impacts [28–30,34–37]. Only those conditions that are the most useful have been selected to create the proposed universal HAFIPES system (from the above list).

3. Proposed Method—An Innovative System

The advantage of the proposed system is its apparent simplicity and the possibility of it being used by people not professionally trained or lacking industry experience. The author decided to follow a similar solution that has been used in many countries around the world for over 30 years, which is the system for assessing groundwater exposure to sources of pollution located on the surface of the area called DRASTIC [38]. The DRASTIC is one of the most well-known groundwater vulnerability mapping methods [39–44], where D, R, A, S, T, I, and C are the seven factors of the DRASTIC method: Depth (to groundwater), Recharge, Aquifer media, Soil, Topography, Impact of vadose zone, and hydraulic Conductivity. DRASTIC is the best and probably the most widely applied scheme for vulnerability assessment. Generally, the DRASTIC system is composed of two parts: (1) the designation of mappable hydrogeological settings, and (2) the application of a numerical scheme for the relative ranking of hydrogeological factors [45]. The hydrogeological setting is a composite description of all the geological and hydrological factors controlling groundwater flow into, through, and out of an area [46].

Recently, geographic information system (GIS) techniques have been widely used in aquifer vulnerability mapping. The major advantage of GIS-based mapping is the combination of data layers and rapid change in the data parameters used in vulnerability classification [47] (Figure 2). In this article, the author used the analogy and principle of this well-known system for groundwater in a new approach to the assessment of the likelihood of an SHPP and the quantification of EP.
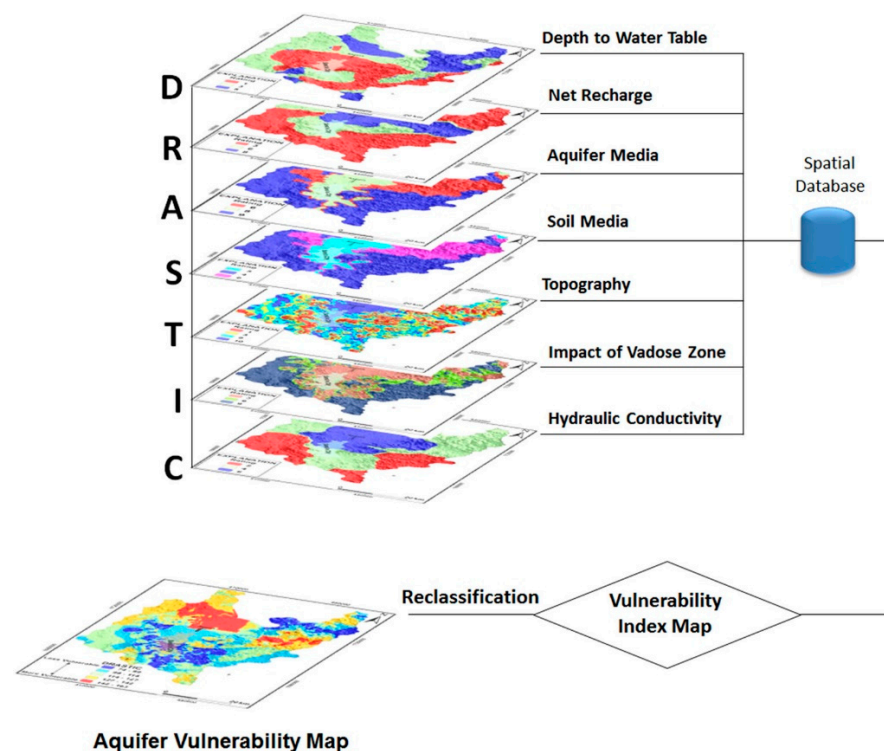

Figure 2. Methodology flowchart for the DRASTIC method [48].

A methodology is described in a way that allows for the evaluation of the possibility of SHPP realization with the important setting. The system has two major parts: the designation of mappable units—hydropower settings—and the superposition of a relative rating system with the proposed name as HAFIPES. Hydropower settings form the basis of the system and incorporate the major hydropower, environmental, and hydrotechnical factors that could decide on whether or not to start or stop the implementation of SHPP.

Most of the hydropower information (all of them without flows that need simple calculations) could be obtained using GIS software from various map portals. These data are commonly available, especially shared by water management organizations in different countries. The obtained or calculated data are combined with HAFIPES Indexes to create a unit for an analyzed cross-section of the river. A survey can cover the entire river, and the results can be graphically displayed on a map. The application of the proposed system to selected sections of rivers, or entire rivers, could result in maps with symbols or colors illustrating sections with variable hydropower potential. The system optimizes the use of existing data to rank sections with the possibility of hydropower plant realization. It could help in direct investigations and in selecting the most promising localizations of SHPP.

3.1. Characteristics of the System

The HAFIPES system has been developed within this publication as a proposition to evaluate the actual prospect of SHPP implementation in the river section based on multi-criteria analysis. In the basic sense, it makes it possible to assess the probability of one specific SHPP being created based on a mathematical analysis performed on known factors. With respect to EP as the total potential of individual SHPP sites on a given stretch of a watercourse (the course of action presented by the author in the previous publications [7,17,18]), it presents an opportunity to assess the real potential of a river or its fragment. Thus, it is a tool useful in developing plans/strategies/assessments of hydropower potential at the local government/national level.

The system should take into account 7 basic factors that have the most significant impact on the feasibility of implementing a hydropower plant or ruling out its construction.

3.2. The Name of the System

The name of the system is an acronym of the first letters of these factors:

H (Head): the existing or potential energy head of a structure;

A (Available Flow): flow as an MF of the proposed river cross-section (with EF, if necessary);

F (Fish): significance of the watercourse for di-environmental fish and migrating organisms;

I (Infrastructure): presence or absence of hydrotechnical infrastructure for adaptation for SHPP;

P (Protected Areas): protected areas and especially valuable for nature;

E (Environmental Flow): the need to preserve the EF;

S (Status): status of SWB according to WFD based on hydromorphological conditions.

3.3. Computation Formula of the HAFIPES Index

The proposed computation formula for the index for the assessment of sustainable SHPP implementation is as follows:

$$\text{HAFIPES} = [H \cdot H_w + (A - E) \cdot A_w + F \cdot F_w + I \cdot I_w] \cdot P \cdot S \tag{1}$$

where H, A, F, I, P, E, S are factors affecting the possibility of SHPP realization, and H_w, F_w, etc. are weight factors according to Table 2.

Table 2. Characteristics of factors in the HAFIPES system.

Factor	Numerical Factor	Weight Factor
H (Head)	in 1 steps with change of 0.5 m i.e., 0.00 m < H < 0.5 m → "0" 0.51 m < H < 1.0 m → "1" 1.01 m < H < 1.5 m → "2", etc.	2
A (Available Flow)	in 1 steps with change of 0.5 m^3/s i.e., 0.01 m^3/s < MF < 0.5 m^3/s → "1" 0.51 m^3/s < MF < 1.0 m^3/s → "2" 1.01 m^3/s < MF < 1.5 m^3/s → "3", etc. If EF is taken into account, the final value is similarly calculated acc. A = MF-EF (2)	2
F (Fish)	F = 1—watercourse not significant for diadromous fish F = 0—watercourse significant for diadromous fish	1
I (Infrastructure)	I = 0 with no infrastructure I = 1 for historical infrastructure to be reconstructed I = 2 for existing operational infrastructure	3
P (Protected Areas)	P = 0 for wildlife nature reservations and areas of strict protection as well as others whose protection objectives are directly in conflict with the SHPP implementation P = 1 for national parks P = 2 for Natura 2000 areas and landscape parks P = 3 for protected landscape areas and ecological lands P = 5 for areas not covered by any form of nature protection	-
E (Environmental Flow)	added to the formula for A	2—along with A
S (Status)	S = 0, when the SWB status according to WFD based on hydromorphological criteria is deemed bad S = 1, when the SWB status according to WFD based on hydromorphological criteria is deemed good	-

Factors P and S have been isolated in the formula as those that can completely block the implementation of SHPP (Figure 3). The mathematical computation of the values of the HAFIPES index in cases where they are equal to zero leads to the resulting possibility of zero. Other factors are included in brackets, which is one of the factors of the proposed product, together with the appropriate weighting factors listed in Table 2.
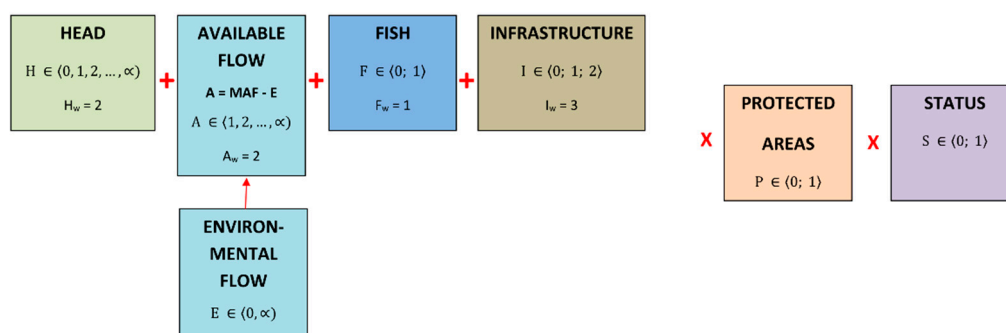
Figure 3. Diagram of the product compute the HAFIPES value.

3.4. Characteristics of the Factors

Factor A takes into account the need to preserve EF in the cross-section of the watercourse when it is necessary (e.g., a power plant with the obligation to keep EF in the main stream or a power plant equipped with a pass in which EF flows). This dependence is introduced in the below Formula (2).

The following assumptions form the basis of the proposed HAFIPES system:

- Theoretically, every river cross-section has hydropower potential;
- Technically, construction of a hydropower plant is possible in every river section;
- The economic evaluation of hydropower project implementation is carried out on a case-by-case basis and depends on the financial circumstances of the investor (own free financial resources, creditworthiness, etc.); therefore, it is not included in the HAFIPES system. It should be supplementary, independent, and based on individual input data of a specific investor; political conditions vary from country to country. This could also affect the possibility. In my opinion, based on experience, the political conditions cannot be implemented in the HAFIPES system in a simple way. It is important to remember that the proposed system is presented as a simple and easy-to-use model. This method is new, unknown as of yet, and to be further developed in the future. At the moment, this methodology is based on expert opinion, experience, and knowledge.

Each factor included in the system has been assigned a certain numerical value according to the following criteria:

- No limit range has been set for H and A factors. For each subsequent step (equal to 0.5 m for H and 0.5 m^3/s with reference to A), the next rank value is assigned.
- For the need to preserve the EF, a correction was made in the formula (1) by subtracting the value valid for passing the unproductive EF from the value A = MF for the cross-section of the watercourse, i.e.,

$$A = MF - EF \qquad (2)$$

- For factor F, two possible values are set: "1" for a watercourse not designated as significant for diadromous fish and "0" for water organisms important for migration. The value "0" is included in Formula (1) not as a separate factor, but among the group of factors, and thus the assignment of the value "0" to it does not disqualify a location from the implementation of SHPP,
- For factor I, three possible values are set: "0" for the lack of infrastructure, "1" for the existence of historical infrastructure obligatory to be reconstructed, and "2" for the existing infrastructure that can be adapted without significant financial outlays for construction works. Similarly as for factor F, the value of "0" has been included in Formula (1), not as a separate factor, but among a group of factors, and thus the assignment of the value "0" to it does not disqualify a location from the implementation of SHPP,
- For factor P, the value "0" is assigned to strict protection areas (wildlife nature reservations or other, for which the implementation of SHPP means collision with conservation objectives). In this case, this factor was isolated in Formula (1), and giving it a value of "0" makes the estimation of the possibility of realizing the SHPP impossible (P = 0 → EP = 0). The remaining protected areas have rankings with the increase in their level of protection, and thus the potential prohibitions on the implementation of new investments. This means that recognizing the status and possible collision is necessary for the correct assessment of the value of the factor. In different countries, the system of protecting nature (especially wildlife nature reserve) might be different, but the proposed ranking factors seem to be the most universal. The final decision depends on the researcher who could assess the value of the factor based on their own recognition of the status of the analyzed protected area,
- For factor S, two values are set: "0" when the status according to WFD based on hydromorphological criteria is deemed bad and "1" when it is deemed good. It is extremely important to remember that in the case of a good SWB status as well, the proposed investment cannot affect the loss of this status. The value of the factor equal to "0" means that another investment that deepens the hydromorphological continuity of the watercourse will make it difficult to achieve environmental objectives for SWB and thus it will not be implemented (a decision on the environmental conditions

of consent for the investment will not be granted). This factor was introduced as a separate one in the formula (1), where for the zero value, the possibility of SHPP realization is equal to zero (S = 0, EP = 0).

As the impact of each factor included in the HAFIPES system has a different impact on the final score, in addition to the coefficients, additional weighting factors (H_w, A_w, etc.) that differentiate individual factors in terms of their importance for the prospects of a small hydropower project have been added (Table 2).

The weights have been assigned based on the author's knowledge after studying different regions in Poland and the USA. In the proposed HAFIPES algorithm, the weights range from 1 to 3 (1 being the least important). The smallest possible HAFIPES index score is 0, and the highest is not limited (depends on the available flow and head). Lower HPP possibility of implementation translates into a lower index score.

3.5. SHPP Implementation Possibility Categories

The structure of the proposed Equation (1) indicates that the higher the value of the HAFIPES index, the higher the likelihood of success of SHPP implementation. It is also possible that identified barriers (e.g., a reserve status) could completely exclude the possibility of SHPP implementation, and in such a case, the value of the HAFIPES index, according to a properly constructed mathematical formula, will be zero. Table 3 lists four proposed categories of possibility depending on the value of the HAFIPES index. The limits shown in Table 3 are based on several dozen previous studies performed by the author in her scientific and professional activity. A range of categories has been established on the "expert's method" that maximizes suitability. In Section 5, selected case studies that justify the accordance of the categories are presented.

Table 3. HAFIPES index ranges for the possibility of SHPP implementation categories.

Index HAFIPES	Possibility Category	Possibility Explanations
0	I	SHPP implementation impossible
1–25	II	low possibility of SHPP implementation
26–50	III	medium possibility of SHPP implementation
>50	IV	high possibility of SHPP implementation

4. Main Criteria Used in the HAFIPES System: The Actual Possibilities and Risks

4.1. Location within an Area of Strict Protection of Nature

A potential site for a hydropower plant can be analyzed in an area covered by one of the forms of national protection, such as national parks, forest and wild animal nature reserves, landscape parks, protected landscape areas, and ecological lands, or in a protected area with a different status sensitive to water conditions. Within the EU, Natura 2000 areas are also designated as special bird protection areas and special habitat protection areas.

Each assessment of the potential impact of SHPP on the environment includes an analysis of its implementation and functioning in relation to conservation objectives established for the respective protected areas.

According to the gradation of conservation objectives, appropriate forms of areas are assigned to particular categories of protected areas (Table 2). In practice, implementation of SHPP in areas covered by most wild animal nature reserves or strict protection areas, as well as others whose protection objectives are directly in conflict with the implementation of SHPP, is impossible. As shown above, the recognition of the status and possible collision is necessary for the correct assessment of the value of the factor. The final decision depends on the researcher, who would assess the value of the factor based on their own evaluation of the status of the analyzed protected. For areas with the highest degree of protection excluding any human intervention in the environment, Formula (1), irrespective of the values of the variables H, A, F, I, E, and S, thus assumes the value of "0" due to the fact that

P = 0. Thus, finally, HAFIPES = 0, which means that a hydropower power plant cannot be implemented in the above river section.

4.2. Status Based on Hydromorphological Criteria

Management of water resources of rivers is currently divided into the so-called surface-water bodies. Each of the separated SWB has its status/condition determined based on biological, physical, chemical, and morphological criteria [49,50]. SHPP are non-emission installations that do not affect the quality of river water, as opposed to, for example, discharging treated wastewater from agglomerations, which often constitutes a serious threat to the aquatic environment [51,52]. However, every single implementation of a hydropower power plant requires the existence/adaptation/construction of a hydrotechnical object from the basics of a permanent partition of the river. For the watercourses designated as bad based on the hydromorphological criterion, the implementation, or even reconstruction, of a new watercourse in the watercourse constitutes aggravation of the already poor condition [53]. Thus, it stands in opposition to the individual's achievement of the environmental goal, which is the assessment of the state as a good state. In practice, SHPP will not be possible under such situations.

For the locations described above, Formula (1), irrespective of the values of the variables H, A, F, I, E, and P, assumes a value equal to "0" due to S being equal to 0; thus, finally, HAFIPES = 0, which means that it is not possible to implement a hydropower plant in the said SWB, for which the status based on the hydromorphological criterion is defined as bad.

4.3. Variable Condition of Hydrotechnical Infrastructures

A frequent criterion used in the search for an optimal location for SHPP is the presence or absence of hydrotechnical infrastructures that can be adapted or reconstructed for SHPP. In domestic practice, under the prevailing conditions in Poland, priority is given to places where weirs or dams are in operation, or where they were in the past and their remains have survived to this day [54]. With regard to changes in the aquatic environment in the cases where the infrastructure (or its residues) are located on the river, it is assumed that the loss of the flow of the watercourse has already occurred and the state of the environment has already stabilized. Implementation of SHPP would not aggravate such conditions, and, additionally, the possibility of equipping the structure with an effective pass constitutes an added advantage for the environment. The existence of hydrotechnical development does not require the introduction of rapid negative changes in the water ecosystem of the watercourse and adjacent areas.

Protection of optimal living conditions of aquatic organisms is a priority connected with the management and protection of water resources. It is absolutely necessary to provide the entire spectrum of the variability of hydrological conditions (water levels and flows) in order to guarantee the maintenance of the full life cycle of organisms [55–57]. These requirements are usually fulfilled in the case of natural watercourses where no significant human pressure is observed in the catchments. The problem is with the catchments in which hydraulics structures that may adversely affect the living conditions of aquatic organisms are planned or already exist. Hydropower plants are one of such facilities.

In many countries (Poland included), there is no direct prohibition of implementing hydrotechnical constructions solely for the needs of electricity production from water energy, although implementation of such projects is difficult in practice, and in these cases, factor I was assigned a value of "0". For indirect situations, when the historical remains of the hydrotechnical structure are located in the watercourse, Factor I is assigned the value of 1. The best situation is when the prospective investor intends to equip an efficient and already operational hydropower dam.

4.4. Environmental Flow

Definitions of EF have been provided in many publications on the subject [58–61]. Instream flow is defined as the amount of water that should be maintained in the river at its cross-sectional minimum for biological and communal needs [62,63]. The general definition present in the general consciousness should be sufficient. The definition is as follows: "the smallest amount of water that must remain in the watercourse to ensure optimal conditions for the existing ecosystems; determined according to a suitably selected criterion based on the knowledge of hydrological and environmental conditions with the maximum respect for biological balance; EF value is not subject to economic criteria, however, when setting it, it is recommended to apply the principle of sustainable development, allowing for socio-economic development while preserving the natural balance" [64].

The term EF has been in vogue in water management for many years. Its non-inclusion is often given as an example of inefficient water management in water pipeline systems supplying water for community and business purposes (e.g., SHPP) [15,65,66].

The lack of a clear methodology for determining the value of EF regulated by national and community laws results in the use of many different methods. Operacz et al. [15] have put forward the current guidelines where EF values are calculated along with the inconveniences based on legal regulations in Poland. EF is of no real value in investment terms; however, it is highly important for environmental protection. The author has come to the conclusion that proper calculation should be a compromise between the protection of the environment and the economics of the investment. The objective of Książek et al.'s [67] research was to compare selected hydrological and hydraulic methods and determine a scientifically acceptable and cost-effective way to EF. This parameter was calculated using conventional hydrological methods: Tennant's and Tessman's flow duration curve and hydraulic methods; wetted perimeter method, a method based directly on ichthyofauna habitat requirements (spawn and migration); the novel combined hydraulic, and hydrological method, which relates to flow hydraulics based directly on ichthyofauna habitat conditions. The methods presented in papers [63–71] can be applied in the water management legislative process. The obligation to determine the EF value is provided for by the national law in proceedings aimed at issuing water permits in the use of surface water. Thus, it is the amount of water that usually cannot be used in the planned project, which directly affects the economy of the investment. In practice, calculations according to a suitably selected criterion, based on available publications on the subject matter, are the most commonly used. In the absence of unambiguous guidelines, a large number of methods allow for a certain freedom in the choice of calculation method. Availability of hydrological input data for a watercourse in question is also limited. Unquestionably, based on Water Law [63], the method based on the 50% of MALF is the one currently universally used in Polish practice.

In the SHPP potential/probability assessment method, the EF value should be chosen according to an appropriate criterion, and the selected EF quantification method must be supported by justification. With reference to the mathematical formula (1), the value of EF in the formula reduces the amount of water available for energy management, which is in line with the generally applicable methodology. EF is the amount of unproductive water energy. In the case where SHPP does not require implementation of a fish pass and the method of using water provides water filling both the upper and lower weir stand, EF may hence be omitted. In such a situation, A is equal to F—the flow of the river.

5. Case Studies

A few case studies for prospective SHPPs have been chosen to assess the HAFIPES index. They were selected to prove the accordance of the categories of the HAFIPES index, so different scenarios are been presented below (for high or medium possibility and for impossible implementation of SHPP). The proposed system was selected for the determination of the prospect of its implementation, as this will make it possible to quickly provide guidance in making decisions about further works or abandoning this location at

no cost. To calculate the value of the HAFIPES index, the necessary information in formula (1) is needed.

Interesting locations for a prospective SHPP are in the Szreniawa river in southern Poland (Figure 4). In Jazdowiczki, there is a mill in the said area, along with a mooring bridge, which, despite being closed for several years, has equipment in working condition that may be used at any time. The mill is built next to a concrete, six-hole weir with wooden stacks with a height of 2.0 m. The facility was built in 1933 and thoroughly modernized in the 1960s. The second location of the potential SHPP is also interesting, on the Szreniawa river in southern Poland (Figure 4), but in Jaksice, there is no hydrotechnical infrastructure in this section. The once existing wooden weir with a height of the head was dismantled and considered to be an unlicensed structure. The location of SHPP in Rudawica on the river Kwisa in the western part of Poland (Figure 5) is theoretically interesting for the potential investor. The SHPP proposed together with the damming weir is located within the special conservation area of Natura 2000 habitats—Dolina Dolnej Kwisy PLH020050—and within the special protection area of Natura 2000—Bory Dolnośląskie PLB020005—as well as in the protected landscape area 34—Bory Dolnośląskie. The planned power plant is located upstream of the former mill channel. The existence of the mill can be documented from the 17th century. The mill channel was filled with water due to the accumulation of water in Kwisa through a concrete weir. The dam was destroyed after 1945; as a result, concrete blocks and debris still lie on the bottom of the river. Until 1945, the said canal brought water to the turbine of the now-defunct factory. The detailed maps of their locations are shown in Figures 4 and 5. The collected input data for estimating the HAFIPES index value are presented in Table 4.
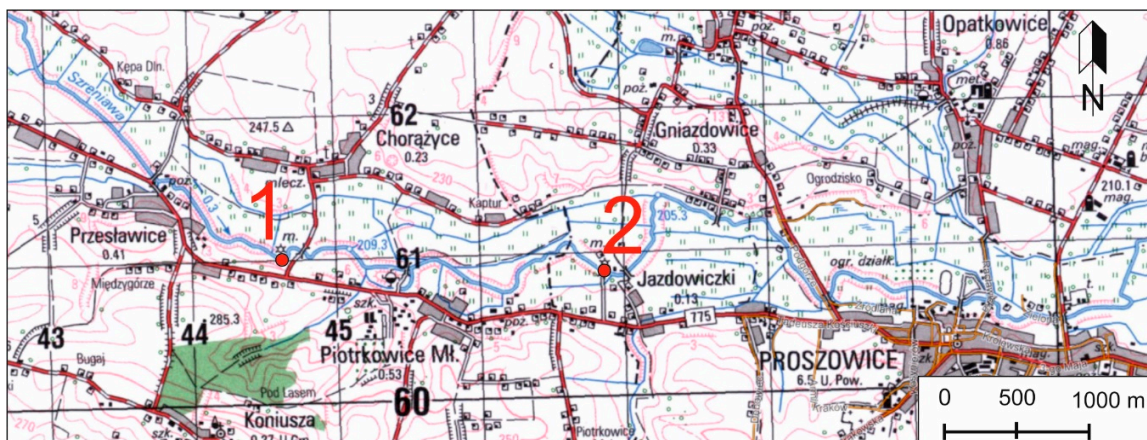

Figure 4. Location of potential SHPP Jaksice (1) and Jazdowiczki (2).

Figure 5. Location of the proposed SHPP Rudawica.

Table 4. Values of factors in the HAFIPES system for prospective SHPPs.

Factor	Weight Factor	Name of Location		
		Jazdowiczki on Szreniawa River	Jaksice on Szreniawa River	Rudawica on Kwisa River
H (Head)	2	head = 2.0 m → H = 3	head potential = 1.0 m → H = 1	head potential = 3.0 m → H = 5
A (Available Flow)	2	MF = 1.5 m³/s; MLF = 0.7 m³/s EF as 50% of MLF [51] A = MF-EF = 1.5–0.35 m³/s → A = 3	MF = 1.5 m³/s; MLF = 0.7 m³/s E as 50% of MLF [51] A = MF-EF = 1.5–0.35 m³/s → A = 3	MF = 13.0 m³/s; MLF = 6.7 m³/s EF as 50% of MLF [51] thus A = MF-EF = 13.0–3.35 m³/s → A = 20
F (Fish)	1	F = 1—watercourse not significant for diadromous fish	F = 1—watercourse not significant for diadromous fish	F = 1—watercourse not significant for diadromous fish
I (Infrastructure)	3	I = 2 for full existing infrastructure	I = 1 for historical infrastructure to be reconstructed	I = 1 for historical infrastructure to be reconstructed
P (Protected Areas)	-	P = 3 for the Miechowska Upland Protected Landscape	P = 3 for the Miechowska Upland Protected Landscape	P = 0 for the Bory Dolnośląskie Protected Landscape
E (Environmental Flow)	2—along with A	added to the formula for A	added to the formula for A	added to the formula for A
S (Status)	-	S = 1, the SWB defined as good	S = 1, the SWB defined as good	S = 1, the SWB status defined as good
HAFIPES index		57	36	0
Possibility category acc. Table 3		IV (high)	III (medium)	I (impossible)

6. Discussion

In the current paper, the author has highlighted the fact that there is a gap in the literature on similar range systems to assess the index for the assessment of sustainable SHPP possibility of implementations; there is no means of quantifying and qualifying the possibility of successful implementation of the hydropower plant. The main conditions and factors are described in general terms. Hydropower schemes are site-specific technology for harnessing water power based on the location where the power could be generated [72].

Evans et al. [35] have proposed accounting for selected sustainability indicators for RES, including hydropower. In the published paper, the technology has been ranked from 1 to 4, with 1 being the best technology for that indicator. The authors compared the total value of ranking and came to the conclusion that wind power is the most sustainable, followed by hydropower, photovoltaics, and last of all geothermal.

The relative ranking proposed by Evans et al. [35] was provided using data collected from an extensive range of literature and only considers the global international conditions. The proposed system HAFIPES is based on selected main criteria, which are extensively explored in previously published papers on the subject of hydropower in many countries. In most of the papers, authors have only described the possible limitations, barriers, and risks as the only way to understand their significance. As a result of such an investigation, there is a descriptive document. In my opinion, the proposed range system constitutes a simpler, comprehensible, and universal alternative for quantifying the possibility of SHPP implementation. HAFIPES system application is an uncomplicated method used to obtain

one score from the proposed Equation (1). Additionally, the author has proposed a real equation with a weight factor, not just a rank value alone, like in Evans et al. paper [35].

In conclusion, the result of the HAFIPES assessment is one equation consisting of four categories of possibility as presented in Table 3. The status of possibility provides guidance on how to proceed with SHPP realizations (Figure 6).
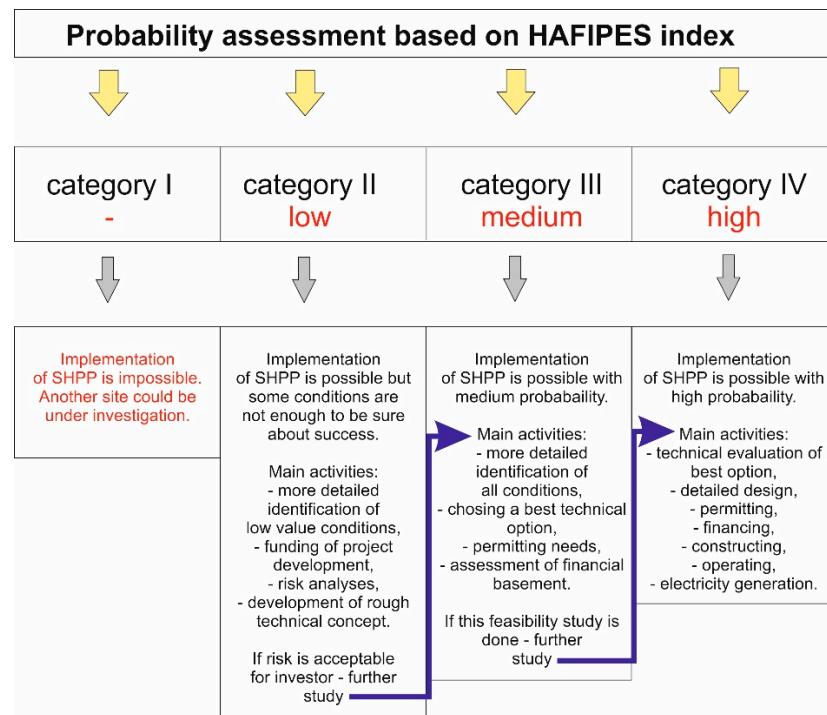

Figure 6. SHPPs development steps based on probability assessment.

7. Conclusions

Water energy, one of the types of RES, is currently undergoing intensive development in many countries with many potential investors looking for locations to implement SHPP. The first initial assessment is usually based on just two criteria alone: available river flow treated as MAF and potential energy head H. Most often, this assessment is overly optimistic, as it does not factor in a number of other criteria that could reduce the forecast amount of electricity produced (EF omission). In many situations, the proposed SHPP will not be constructed at all due to, for example, collision with the objectives of designated protected areas, or due to the hydromorphological criterion for the assessment of the watercourse.

In the course of scientific studies supported by practical experience on the development of concepts and reports on the environmental impact and water legal permits for SHPP, a lack of a uniform methodology to estimate the possibility of SHPP implementation has been noted by the author. The conclusion of research and studies is a simple mathematical formula that takes into account all the relevant factors/criteria along with the determination of their significance weights. The proposed system, named HAFIPES, puts forward a range of possibilities.

The results can help select the most suitable places for SHPP realization. In the subsequent stage, quantitative assessment of hydropower potential (e.g., technical or economic potential) could be done on a case-by-case basis. The proposed HAFIPES system is a range standardized system that brings out the preliminary information without having to calculate hydropower potential in MWh. The results of the "HAFIPES index ranges for the possibility of SHPP implementation categories" have no units.

Most of the hydropower information (all of them except the flows that need simple calculations) can be obtained from various map portals using GIS software. These data are

freely available, and in addition, usually shared by water management organizations in different countries. Derived or calculated data are combined with HAFIPES Indexes to create a unit for an analyzed cross-section of the river. A survey can cover the entire river and the results can be graphically displayed on a map. Application of the proposed system to selected sections of rivers, or entire river length, could result in maps with symbols or colors illustrating different sections with variable hydropower potential. The system optimizes the use of existing data to rank the sections with the potential of hydropower plant realization. It could help in direct appraisal and in selecting the most promising localizations of SHPP.

Being simple, consistent, and based on real conditions, the presented method adopted to determine the possibility of SHPP implementation could be used universally. No such methodology has yet been proposed, either in scientific or industry studies, and this represents an extremely perceptible lack. The wide possibilities of using the HAFIPES system by individual investors and local government units or scientists are obvious. The author hopes that the proposed HAFIPES system will be frequently used, leading to improved quality of studies in the hydropower potential of watercourses and providing a quick, inexpensive analysis for individual investors in support of making investment decisions. The proposed system is based on terms that are commonly used all over the world. In other areas, it can be used with equal success since only universal criteria have been chosen. The proposed method can be implemented in every country and can be improved/extended with new factors based on individual criteria existing in this area. These could include, e.g., unusual legal procedure, ethnic reserves, monuments, government support, and the impact of other important aquatic species. After analyzing the advantages and disadvantages of this research method, it can be summarized that it is worth propagating and recommending it for the estimation of hydropower potential. The author believes that the novel contribution of the paper, which is the innovative range system, will be accepted for day-to-day use.

Abbreviations

HPP	Hydropower plant
SHPP	Small hydropower plant
WFD	Water Framework Directive
SWB	Surface water body
EU	European Union
RE	Renewable energy
RES	Renewable energy sources
GIS	Geographics information system
TP	theoretical potential [kWh]
TCHP	technical potential [kWh]
EP	effective potential [kWh]
MF	mean flow [m^3/s]
MLF	mean low flow [m^3/s]
H	head [m]
A	available flow [m^3/s]
EF	environmental flow [m^3/s]

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