Decision Matrix for Pilot plant

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A	See Cover Page	All	First Issue
B	11/2024	All	Second issue

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Abbreviations and acronyms

Acronym	Description
EU	European Union
DW	Demineralized Water
HPP	Hydrogen production plant
HTSE	High temperature steam electrolysis
LCOH	Levelized cost of hydrogen
LTE	Low temperature electrolysis
NPP	Nuclear power plant
WP	Work Package

1 Summary

The objective of the Work package 5 is to choose the most suitable location for nuclear powered hydrogen cogeneration from all European candidates.

The first step in selecting a suitable site for the pilot project is to develop a universal decision matrix, which is the objective of this document. For this purpose, specific criteria are determined to allow the selection of the most appropriate concept for the integration of hydrogen technologies in Nuclear power plants (NPPs). Based on Work Package 1 – Work package 4 (WP1-WP4) is prepared a summary of these criteria. Preliminary the criteria are divided into 6 groups.

Technical criteria

- by these criteria it is evaluated the possibility of obtaining required resources from NPP
- also, it is evaluated the technical design of the HPP

Modification criteria

- by these criteria it is evaluated necessary modifications of NPP to connect to HPP

Licensing criteria

- by these criteria it is evaluated necessary steps for licensing HPP with connection to NPP

Personnel criteria

- by these criteria it is evaluated requirements for the operational personnel of the NPP and HPP

Storage criteria

- by these criteria it is evaluated the requirements for storage of the produced hydrogen

Transport criteria

- by these criteria it is evaluated the method of transporting of produced hydrogen

Each criterion will be considered, allowing its weight in the cost of hydrogen production to be correctly determined.

It is not possible to calculate detailed cost of the solution, but it is possible to compare which of the proposed solutions and locations are more suitable at this stage. Then it is possible to compare realistic scenarios for each candidate NPP. As there are 9 possible scenarios (level of integration) proposed in Deliverable 1.2 [5] and 3 main electrolysis technologies, several calculations will have to be performed for each candidate plant to decide on the most suitable solution.

For performing matrix evaluation, it is necessary to collect a lot of data from each candidate NPP. For example, the potential location of HPP placement, technical possibilities of supply of different resources, their quality and cost and approximate schemes of NPP modifications.

The matrix is designed as a tool for universal application in European NPPs. Therefore, it can also be applied after the end of the NPHyCo project. In the final stages of Task 5 only the site selected according to the conditions of the decision matrix is processed in more detail. The Decision Matrix is primarily a comparison tool but can also be useful for a decision which scenario and technology is better for one candidate at the NPP-HPP project. The weights of criteria in this Decision matrix are set for low temperature electrolysis technology. But the matrix can be used also for HTSE, if the weights of the criteria will be adjusted.

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The Assessment of candidate conditions can only be performed on the current state, current conditions and given data by the candidate: Licensing conditions, resources prices, potential hydrogen customers, transportation conditions, NPP operating conditions, personnel costs, social and political conditions.

Conditions for some criteria can change significantly over the lifetime of the HPP. Predicting changes in any criterion over a long-term period (comparable to the lifetime of the HPP) can lead to significant errors. There is currently no reliable tool for such predictions. Accordingly, the decision matrix is designed to work for current conditions and short-term plans. For medium- and long-term predictions, uncertainty is high, and the probability of error can occur. This is because many of the conditions inherent in such a prediction may change significantly over a long period of time. For example, prices for basic resources (electricity, water) can change significantly within 5-10 years. It is impossible to predict the inflation rate, other national and international economic indicators. There is a probability of changes in conditions and ways of hydrogen transportation. Market research performed today may lose its relevance in the long-term period. Changes in national concepts of nuclear power development, tax systems, safety issues and many other things may make today's economic assessments irrelevant.

A comparison of possible candidate NPPs will be made for each realistic scenario and type of electrolyser for each site. This will give us the possibility to select the most suitable scenario and electrolyser technology for each power plant. Then we can compare the plants with each other.

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2 General principles for assessing the criteria for the different components.

To carry out the evaluation, each candidate site should identify its status in each criteria area for subsequent evaluation. The mutual evaluation will select the most realistic possible configuration for the location of the HPP and the use of resources specific to the candidate site. The criteria will be evaluated for this realistic configuration. The evaluation for any candidate site may be repeated with other realistic conditions of the integration scenario or the use of NPP resources if the optimal conditions (in terms of maximum score) cannot be determined in advance. Those conditions with maximum score values determined from the decision matrix are considered optimal and final for the specific candidate site.

In the following, the methodology for evaluating the decision matrix criteria is outlined, the methods and elements of the evaluation are briefly described, and a comparison of candidate sites is made.

The assessment of the level of applicability of NPPs for NPP-HPP cogeneration is performed by comparing existing conditions of the NPP and prospective conditions of the HPP according to a set of key criteria. The evaluation criteria chosen are:

For NPPs:

- **conditions of resource availability from NPPs (technical criteria, resources reliability);**
- **conditions of NPP modifications;**
- **NPP license conditions;**
- **conditions of NPP equipment operation (if additional personnel needed);**

For the HPP:

- **HPP configuration;**
- **conditions of HPP equipment operation (if additional personnel needed);**
- **HPP license conditions;**

Logistics:

- **hydrogen storage conditions;**
- **hydrogen transport conditions**

2.1 A general approach to performing a criteria assessment.

The total attractiveness of an NPP site for inclusion in the list of potential candidates for HPP placement is assessed by the sum of points scored in the decision matrix.

According to the Deliverable 3.2 [1] approximately 70-80% of the total costs of hydrogen production at HPP with low temperature technology are costs of electricity, what can be seen for example in Figure 1 (one of the figures from Deliverable 3.2.[1]).

Next key resources, demineralized water and cooling water was identified according to their cost and amount which is necessary for operation of the HPP. Only a small part of the cost is attributable to other resources.

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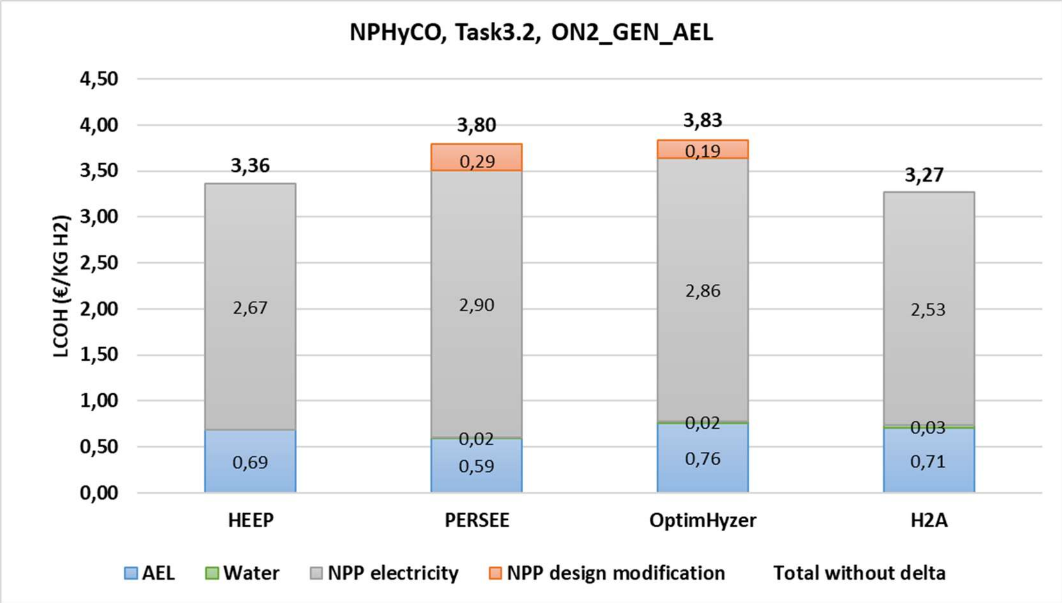

Figure 1: Results of ON2 scenario (maximum degree of integration: electrical supply, cooling water system, demineralized water system and wastewater system)

Thus, the approximate operational cost ratios (weights) of resources should be considered to estimate the matrix resources:

Table 1 Relative proportions of resource costs

	Resources	Relative proportions (weights) of operational resources for HPP
E / S	Electricity / Steam	0.90
C	Cooling water	0.05
D	Demineralized Water	0.04
T	Tap water	0.01
H	Chilled water	
W	Wastewater	
A	Pressurized air	
N	Nitrogen	

3 Methodology for assessing the criteria of the universal matrix.

3.1 Assessing the availability of technical resources

Table 2 Resource availability requirements

E	Electricity	**Key resource**. The possibility of long-term redundant power supply (40-45 MW) from the candidate site equipment (NPP), 6 (or 6 and 0.4) kV is assessed.
S	Steam	**For the HTSE is a key resource.** The ability to supply the resource is only assessed if it is required to be used in the process cycle of the HPP.
D	Demineralized Water (DW)/Feedwater	**Key resource.** The possibility of long-term supply of the HPP with a flow rate of 6 tons/hour from the candidate site equipment (NPP) is assessed. The need for installation of equipment at the HPP for purification of the supplied DW to the required parameters is defined as a significant adjustment of parameters.
T	Tap water	Not a major resource. The possibility of supply from the candidate site equipment (NPP) is assessed. Tap water in this meaning is used only for sanitary facilities not as a source for demineralized water.
C	Cooling water	**Key resource.** The possibility of long-term supply of cooling water with a flow rate of 750-900 tons/hour from the candidate site equipment (NPP) is assessed. The necessity to install at the HPP the equipment for correction of parameters of supplied water (temperature, pressure, flow rate - except for valves) to the required parameters is defined as a significant correction of parameters.
H	Chilled water	Not a major resource. The possibility of supply from the candidate site equipment (NPP) is assessed.
W	Wastewater	Not a major resource. The possibility of using the candidate site equipment (NPP) for diversion and treatment/disposal of liquid waste of the HPP with a flow rate of 2.5 tons/hour is assessed.
A	Pressurized air	Not a major resource. The possibility of using the candidate site equipment (NPP) to supply the resource to the HPP with a flow rate of 190 m^3 /hour is assessed.
N	Nitrogen	Not a major resource. The possibility of using the candidate site equipment (NPP) to supply the resource to the HPP with a flow rate (approx.) of 0.045 tons/hour is assessed.

The values in this table are for the evaluation of the HPP pilot project – 30MW electrolyser. If another HPP project will be applied, the values should be revised.

The availability of HPP resources from the candidate site (NPP) is assessed based on Table 2. The selection of the appropriate configuration determines the value of the NPP's contribution to the ability to provide HPP resources. The maximum value of the criterion, with a very high NPP ability to provide a resource to the HPP, and the minimum value, with a very low NPP ability.

Table 3 Conditions of resource availability from NPPs

Score	Availability of technical resources
Very high	It is possible to supply all resources (including 6 and 0.4 kV electricity) from an external source (NPP) to the HPP with minor adjustments of parameters
High	It is possible to continuously supply at least electricity (6 and 0.4 kV), demineralized water and cooling water and steam (for HTSE) from an external source (NPP) to the HPP in needed volume, without limitation of producing on the NPP.
Average	There is a possibility of continuous supply of three key resources (and steam for HTSE) from an external source (NPP) to the HPP with significant adjustments (including 6 kV electricity)
Low	Continuous supply of at least one of the major resources from an external source (NPP) to the HPP is available
Very low	There is no possibility of supplying several resources from an external source (NPP) to the HPP

When assessing the availability of HPP resources, the redundancy or reliability of their supply to the HPP should also be considered. Reliability also depends on the interchangeability of resource sources. In the case of NPPs, this is determined by the number of units at the candidate site. Thus, a single-unit NPP may be considered less reliable in terms of resource supply due to the lack of redundancy in the event of a unit shutdown or outage of critical equipment. Therefore, the reliability coefficient (multi-unit) of NPP is also established.

Table 4 Resources reliability factor.

Number of units at NPP site	Score
1	Low
2	Average
3 or more	High

3.2 Conditions of NPP modifications

The conditions for modification of NPP equipment are assessed in terms of the degree of applicability of the candidate site (NPP) to be used together with the HPP for hydrogen production.

The approximate scope (readiness) of modifications to NPP equipment and systems to supply the HPP with the necessary resources, with the required volumes and adequate quality from the candidate site (NPP) is estimated based on Table 5. The selection of the appropriate configuration determines the value of the technical and organizational readiness of the NPP to perform the necessary modifications to provide the HPP with resources. The maximum value of the criterion, at very high technical readiness of the NPP and insignificant volumes of necessary modifications of NPP systems, the minimum value, at very low technical readiness and large volumes of necessary modifications. Initially, modifications for each resource should be evaluated and then a general picture is compiled summarizing all resources.

Table 5 List of NPP systems for modifications

E	Electricity	Key resource. The relative volume of modifications of NPP electrical equipment for long-term redundant power supply (40-45 MW) from the candidate site equipment (NPP), 6 (or 6 and 0.4) kV is estimated. The average value is taken as the absence of installed redundant equipment applicable for the system modification, without significant technical and organizational problems in performing the modification.
S	Steam	Modification of candidate site equipment and systems (NPPs) is assessed only if it is necessary to use it in the process cycle of the HPP.
D	Demineralized Water/ Feedwater	Key resource. The relative volume of modifications of NPP DW equipment for reliable supply of HPP with a flow rate of 6 tons/hour from the candidate site equipment (NPP) is estimated. Absence of installed reserve equipment applicable for system modification without significant technical and organizational problems of modification is taken as an average value. The need for modification is assessed both for supplying the required flow rate of DW and the quality of DW for HPP needs.
T	Tap water	Not a major resource. The relative volume of modifications of equipment and systems of the candidate site (NPP) to provide the HPP with domestic water is assessed. Absence of installed reserve equipment applicable for system modification without significant technical and organizational problems of modification execution is taken as an average value.
C	Cooling water	Key resource. The relative volume of modifications of equipment and systems of the candidate site (NPP) to provide cooling water to the HPP is assessed. The average value is taken as the absence of installed reserve equipment applicable for system modification, without significant technical and organizational problems of modification. The criterion value can be recognized as high if the NPP recycling water supply systems are supposed to be used for HPP without critical reduction of water consumption for NPP equipment, which requires reconstruction of the system with installation of additional pumps. Decrease of the criterion value can be assessed if additional water supply systems are required or significant reconstructions in the schemes, including laying of additional pipelines along long and complicated routes.
H	Chilled water	Not a primary resource. The possibility of modification of candidate site equipment (NPP) is assessed. The relative volume of modifications of equipment and systems of the candidate site (NPP) to provide HPP with chilled water is assessed. The absence of installed redundant equipment applicable for system modification without significant technical and organizational problems of modification is taken as an average value.
W	Wastewater	Not a major resource. Evaluates the feasibility of modifying equipment for the diversion and treatment/disposal of liquid wastes from the HPP of the candidate site (NPP). The relative number of modifications to the candidate site's (NPP) equipment and systems to integrate the HPP's water disposal system with a similar system at the NPP is assessed. The average value is taken as the absence of

		installed redundant equipment applicable to the modification of the system, without significant technical and organizational problems in performing the modification. Key influences may include the complexity and length of additional pipework and the installation of additional pumping or filtration equipment.
A	Pressurized air	Not a major resource. The relative volume of modifications of equipment and systems of the candidate site (NPP) to provide the HPP with compressed air is assessed. The average value is taken as the absence of installed redundant equipment applicable for system modification, without significant technical and organizational problems in performing the modification. The complexity of routing and length of additional pipework, as well as the installation of additional equipment, can have a key impact.
N	Nitrogen	Not a major resource. The relative volume of modifications of equipment and systems of the candidate site (NPP) to provide the HPP with nitrogen is assessed. The absence of installed redundant equipment applicable for system modification without significant technical and organizational problems in performing the modification is taken as an average value. The complexity of routing and length of additional pipework, as well as the installation of additional equipment, can have a key impact.

The base modification conditions of each candidate site (NPP) are defined as the Table 6.

Table 6 Conditions of NPP modifications

Score	Readiness for modifications
Very high	Very high - no need to modify NPP systems with basic resources.
High	High - minor modifications of NPP systems with basic resources are required, without affecting safety.
Average	Average - modifications of some NPP systems with safety impact or installation of additional equipment on several NPP systems.
Low	Low - significant modifications on all NPP systems providing the main HPP resources.
Very low	Very low - impossibility to modify at least one of the main resources without significant impact on safety or reliability of NPP operation.

3.3 NPP licensing conditions

The licensing conditions of a candidate site (NPP) are assessed, considering design adjustments, modifications and the HPP siting scenario. The complexity of the licensing process established by national institutions for certain changes related to the hydrogen production process at the selected candidate site (NPP) is assessed. The assessment is performed based on the analysis of national legislation, national requirements and limitations to the licensing process.

Table 7 NPP license conditions

Score	License conditions
Very high	No restrictions.
High	Restrictions are minor.
Average	License conditions are clear and can be resolved.
Low	License conditions are not clearly defined or restrictions are significant.
Very low	There's an explicit prohibition.

3.4 Conditions of NPP equipment operation

The conditions of the involvement of NPP personnel in the operation of systems and equipment of NPPs supplying resources for HPP are assessed. After possible modifications of the systems, the service area of the modified systems can be extended or made more complicated. The criterion represents the extent to which the candidate site (NPP) staff can be utilized to maintain the modified circuits. Only the feasibility of maintenance at the NPP site or by NPP personnel is assessed. The assessment is based on an analysis of the complexity of the modifications and, accordingly, expert judgements of the extent to which NPP personnel can be utilized.

The costs of the development and adjustment of documentation and training of NPP personnel due to modifications of NPP equipment can potentially be compared with the EU average costs for such tasks at different NPPs. However, these costs depend on many specific factors. It is not currently possible to obtain such baseline data within the scope of this project. An indirect indicator of the relative costs of personnel and documentation are the complexity of modifications, the HPP placement scenario, the specifics of the documentation development process and personnel training. To clarify the relative level of costs, the method of expert judgement is used.

As an input data from the candidate NPP it is necessary to know the staffing capabilities and knowledge of existing staff.

Table 8 Conditions of NPP equipment operation

Score	NPP Personnel
Very high	NPP personnel are available and no additional personnel are required. No training/adjustment of documentation required. No additional staff costs required.
High	NPP personnel are available, minor additional personnel may be required. Low costs for additional NPP personnel. Low costs for training and documentation.
Average	NPP personnel are partially available, additional personnel are required to supply resources to the HPP. Average costs. Adjustment of documents, training, regular and additional personnel is required. Increase of NPP staff.
Low	NPP personnel are not available, separate personnel are required to supply resources to HPPs. Increased staffing due to separate personnel maintaining the resource delivery circuits at the NPP site.
Very low	NPP personnel are not available, additional personnel to supply resources to HPP cannot service NPP equipment. No costs are required. Maintenance of resource supply schemes from NPPs to HPPs is not possible.

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3.5 HPP configuration

The HPP is assessed regarding the availability and quality of resources from the candidate site (NPP) and modifications to NPP systems. If it is impractical or impossible to supply resources of the required quality from NPPs or other sources in the immediate vicinity of the HPP, some resources may be generated or upgraded to the required quality directly at the HPP site. Such an arrangement increases the cost of the HPP configuration but may be economically justified if the costs are lower than the cost of modifying NPP systems. It should be evaluated based on the conditions of each candidate site, considering the criteria for resources and modifications considered above for NPPs. The maximum score corresponds to the minimum need for retrofitting of the HPP. A minimum score means that several major resources need to be built in the HPP at once.

The costs of retrofitting the HPP with additional facilities and resources are different, but the relative prices of equipment and services specific to the location of the candidate site should be considered. Preliminary costs for each scenario and technology were calculated in Deliverable 3.1.[2]

Configuration costs are not estimated separately for each system or resource. Based on the baseline condition and the amount of proposed retrofitting, the relative configuration costs of the HPP are estimated.

As an input data from the candidate site, it is necessary to find out the prices of necessary equipment of HPP and the price level for other common equipment and activities (e.g. price of piping, price of installation work, price of documentation, etc.) of HPP

Table 9 HPP configuration

Score	Need for HPP equipment for production
Very high	Very low - maximum resources from NPPs, no need to retrofit HPPs. Basic HPP package, assuming all resources are supplied in sufficient quantities from an external source.
High	Low - minor retrofitting of HPPs with autonomous resources (chillers, pressurized air, wastewater system) is required. Insignificant cost of retrofitting the HPP with non-core resources.
Average	Average - requires additional treatment of basic resources by HPP means (DW), regulation of temperature or pressure of cooling water, electrical equipment (transformers) at the HPP site.
Low	High - retrofitting of the HPP with means of production of at least one of the basic resources (cooling, water, DW, electricity). HPP project includes means of supplying a key resource that requires significant capital or operational resources.
Very low	Very high - several of the key resources are not available from the NPP and must be produced at the HPP.

3.6 Conditions of HPP equipment operation (HPP personnel).

The conditions for maintenance of equipment and technological processes at the HPP site are assessed. The maximum assessment implies the minimum number of personnel on the HPP staff. In this case, the maintenance of the HPP to the maximum extent lies with the NPP personnel. Only for maintenance of the electrolyzer will be in any case the specialized company. At the same time, a few other issues will need to be addressed, including those related to the reliability and safety of the NPP.

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The criterion finally evaluates which scheme of NPP and HPP personnel involvement is the most probable for maintenance of HPP equipment. The assessment is made based on expert judgements.

The costs of developing documentation and training of the HPP personnel are estimated. An indirect indicator of the relative costs of personnel and documentation is the number of personnel servicing HPP, as well as the amount of additional equipment for the HPP to obtain resources of the required quality. To clarify the relative level of costs, the method of expert evaluation is used.

As an input data from the candidate NPP it is necessary to know the staffing capabilities and knowledge of existing staff.

Table 10 Conditions of HPP equipment operation

Score	Personnel for HPPs
Very high	No additional HPP personnel required, all maintenance is performed by NPP personnel.
High	NPP personnel are available to maintain the HPP, a small number of HPP personnel may be required.
Average	HPP personnel are required to manage the HPP process and resources from an external source.
Low	HPP personnel are required to manage the HPP process and the resources generated at HPPs.
Very low	HPP personnel are required to manage the process at HPP and the resources generated at HPP and external resources outside of HPP.

3.7 HPP license conditions

The licensing conditions for HPPs located around the candidate site (NPP) are assessed, considering location adjustments, environmental impact, and other criteria established by national institutions for hazardous or dangerous industrial facilities. The complexity of the established licensing process for such industries in specific conditions is assessed. The assessment is based on the analysis of national legislation, national requirements, and limitations to the licensing process for hazardous or dangerous industries.

Table 11 HPP license conditions

Score	Licensing conditions
Very high	No restrictions on licensing of HPPs
High	Restrictions on licensing of HPPs are insignificant
Average	The license conditions are clear and can be resolved in the usual way
Low	License conditions are not clearly defined or restrictions are significant
Very low	Placement of HPP is prohibited in this location

3.8 Hydrogen storage conditions

The existing and planned conditions for the storage of produced hydrogen prior to its transportation to the consumer are assessed. The level of the criterion depends on storage facilities

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designed to store the maximum amount of hydrogen located at a certain distance from the HPP. Plans for construction of storage facilities and methods of hydrogen transport from the HPP to the storage facility are also considered. The construction of storage facilities, their maintenance, their distance from the HPP and the planned means of transport to the storage facilities can also affect costs in both directions. In addition, given the location of the HPP, the costs of construction and maintenance of storage facilities may also vary, which should be considered in the assessment.

As an input data from the candidate NPP it is necessary to know existing possibilities of hydrogen storage or possibilities of placing the new storage.

Table 12 Hydrogen storage conditions

Score	Hydrogen storage conditions
Very high	There are storage facilities that can be used for new HPP. Low costs of hydrogen delivery to the storage are required. Distance from storage and transportation routes to NPP structures and communications is more than 2 km.
High	Storage facility and transportation routes can be located at a distance of more than 2 km from NPP structures and communications. Low costs of hydrogen delivery to the storage are required.
Average	HPP offsite. Storage location and hydrogen transportation routes from HPP are not defined.
Low	HPP is located at the NPP site.
Very low	HPP is located at the NPP site. Storage location requires additional NPP safety measures or significant costs are required for hydrogen transportation from HPP to storage.

3.9 Hydrogen transport conditions

The existing and planned conditions for transporting the produced hydrogen to the final consumer or intermediate hub are assessed. The level of the criterion depends on the existing modes of transport from the HPP site. Plans to organize different types of hydrogen transport are also considered.

The potential costs of hydrogen transport depend largely on the level of existing or planned conditions. However, the organization of transport, maintenance of facilities and facilities can also influence costs in either direction. In addition, given the location of the HPP, including whether it is in the EU or outside the EU, the costs of transport and maintenance of transport facilities may also differ, which should be considered in the assessment.

As an input data from candidate NPP it is necessary to know the possible consumer of the hydrogen and the selection of one of the hydrogen transport methods.

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Table 13 Hydrogen transport conditions

Score	Hydrogen transport means
Very high	Very high - there are pipelines to transport hydrogen to major consumer areas directly from the HPP or storage site. Or low costs are required to transport hydrogen from the storage site.
High	The hydrogen consumer is confirmed to be more than 2 times the capacity of the HPP.
Average	Consumers and HPP are located within one economic zone/country, and The hydrogen demand is not confirmed to be more than 2 times the capacity of the HPP.
Low	Satisfactory conditions of hydrogen delivery to potential consumers are determined. Consumers and HPP are located within one economic zone/country.
Very low	Consumers and HPP are not located within one economic zone/country, or The hydrogen demand is not confirmed to be more than the capacity of the HPP.

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4 Decision matrix update

4.1 Approach

The purpose of this section is to:

- Determining the mutual influence of each criterion;

- Specifying the contribution of each criterion to the overall evaluation of the candidate;

- Optimization of the estimation algorithm.

The criteria presented above have varying effects on the overall score. In addition, they may overlap in their impact on the final outcome.

The purpose of the matrix is not to perform a cost estimation, but to compare and select from two or more candidates (models defined by realistic configurations) and deliver the best model. Here, the best model is the model for which the LCOH is expected to be lower than the other models under consideration.

The model includes unique main conditions describing:

a. the location of the HPP,

b. the electricity supply scheme for the HPP,

c. the cooling water supply scheme,

d. the demi water supply scheme,

e. the utilization of NPP resources (including approximate costs of modifications and licensing and personnel, reliability of supply, and lifetime of the NPP),

f. the selected HPP base configuration (as appropriate for the selected technology),

g. the additional HPP configuration (in accordance with the selected level of integration with NPP, including analysis of additional HPP personnel),

h. conditions of hydrogen transportation to consumers (distance of intermediate storage, conditions of hydrogen delivery from HPP, conditions of hydrogen delivery from storage to consumers, estimated volumes of delivery to consumers).

These data can be optimized and presented as aggregated assessment areas. The data in the model will help define the conditions for the following criteria:

1. Resource costs from the NPP.

2. Costs of modifications to the NPP.

3. Costs of additional HPP equipment.

4. Logistics costs.

5. Reliability of supply of NPP resources.

These criteria were already included in the first revision of the decision matrix. However, this revision updates the weight of each criterion (based on the analysis and discussion of the results of Tasks 2, 3, 4) and its influence on the final result. In addition, some criteria mutually impact each other and are therefore considered here as combined criteria. This is to avoid duplication of some criteria and consequently distorting the final outcome.

This revision of the decision matrix is developed based on the following principles:

1. Summarized evaluation criteria are established;

2. Each summarized criterion is assigned a preliminary value of base weight (relative weight in LCOH). The values are established based on the results of the Task 3 analysis;

3. Summarized criteria include multiple criteria related to each other that may influence cross-over;

4. Criteria can also be separated into individual ingredients if there are significant differences in their contributions;

5. Some criteria take the form of a factor within a summarized criterion;

6. An evaluation table is developed for each criterion, according to which the criterion value is selected for each NPP (each model);

7. The total value of each summarized criterion characterizes the relative share of that summarized criterion in the total LCOH value for the specific model considered.

8. The total score of NPP (NPP-HPP models) is determined by the sum of values of all summarized criteria for a specific model;

9. The cost structure, advantages and disadvantages of each model are visualized in the decision matrix. The estimates do not pretend to be cost accurate, but they are performed on a uniform methodology and are well presented as a comparison of similar criteria.

10. The optimal model (pilot NPP) is defined as the model with the highest value of the total score.

The basic aggregated structure of hydrogen price considering the main contributors is shown in Table 14. This structure will be the base for further estimation of contributions (weight) of each criterion of the decision matrix for technology of low temperature electrolysis.

Because the HTSE is slightly different technology than LTE so weights of each criterion of the decision matrix must be adjusted for the HTSE technology. From the deliverable 3.2. it can be seen that the electricity costs of this technology do not form such a part of the LCOH as with LTE, but for example the CAPEX calculated in deliverable 3.1 is significantly higher compared to LTE. Also, the price for NPP modification will be different. Next coefficient for which its weight will need to be adjusted is Licencing of NPP, because using of the steam from the NPP will have influence on nuclear safety.

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Table 14 LCOH Base structure.

<table>
<tr><th colspan="2">Total share of LCOH criteria</th><th colspan="5">Structures</th></tr>
<tr><td rowspan="2">Resources</td><td rowspan="2">NB
0.7</td><td>Resource from NPP</td><td>N el
Electricity/steam</td><td>N cw
Cooling water</td><td>N dw
Demi water</td><td>N oth
Other</td></tr>
<tr><td>Reliability of NPP resource supply (coefficient to resource costs)</td><td colspan="2">N5
Number of NPP units</td><td colspan="2">N6
Lifetime of NPP</td></tr>
<tr><td rowspan="2">Modification/ Configuration</td><td rowspan="2">HB
0.1</td><td>Costs of NPP modifications</td><td colspan="2">NPP systems - complexity of modification</td><td colspan="2">Licensing NPP - location</td></tr>
<tr><td>Costs of additional equipment HPP</td><td>Cooling water</td><td>Demi water</td><td colspan="2">Other</td></tr>
<tr><td>Logistic</td><td>LB
0.2</td><td>Logistics costs</td><td colspan="2">Intermediate storage</td><td colspan="2">Transportation from storage to consumer</td></tr>
</table>

4.2 Description of component assessment

4.2.1 Costs of NPP resources - N.

The base weight (**NB**) of these costs is assumed to be about 0.7 of the LCOH.

N depends on the relative costs of each of the resources used for HPP.

The NPP resource costs are estimated as a summation of the possible costs of the key resources - electricity/steam, cooling water, demi water and the remaining resources, given their approximate contribution to the LCOH.

In turn, the relative costs of each of the resources are also weighted by considering the "weight" of the resource in hydrogen production. This "weight" is determined by the resource coefficient indicator (the share of each resource of the total HPP technical resource costs):

N el =0.9 - cost factor for electricity utilization (this means that the contribution of electricity to the structure of all technical resources from NPPs is about 90%);

N cw =0.05 - cost factor for the use of cooling water (contribution of cooling water to the structure of all technical resources from NPPs is about 5%);

N dw =0.04 - cost factor for the use of demi water (contribution of demi water to the structure of all technical resources from NPPs is about 4%);

N oth =0.01 - cost factor for the use of other resources (summary contribution is about 1%).

In addition, the reliability of HPP supply with technical resources is considered. It depends on the stability of NPP equipment operation. If there are several power units at NPPs, the reliability of HPP supply increases (due to increased redundancy of NPP systems supplying resources for HPP). This factor is considered by the coefficient **N5**. The variable coefficient is set according to the weight. Due to redundancy, having only one NPP unit or two units makes more difference in importance than having two or more units.

Residual lifetime of NPP is considered by coefficient **N6**. For multi-unit NPPs, the remaining lifetime of the last operating power unit is considered.

Total costs of NPP resources **N**= NB* (Nel*N1+Ncw*N2+Ndw*N3+Noth*N4) *N5*N6.

Maximum range **N** = (0.513-0.864).

Table 15 Assessment of NPP technical resources.

Base weight of resource costs, **NB**	**0.7**
	Nel=0.9-baseline weight of electricity utilization cost coefficient
Variable coefficient **N1**	**Estimated electricity costs from NPPs**
1.1	High – it is possible to supply of electricity (including 6 and 0.4 kV)/steam (for HTSE) from an external source (NPP) to the HPP at a special low price, with minor adjustments of parameters.
1.0	Average - it is possible to continuously supply of electricity (6 and 0.4 kV)/steam (for HTSE) from an external source (NPP) to the HPP at a market price with minor adjustments of parameters.
0.9	Low - it is possible to continuously supply of electricity/steam (for HTSE) from a grid to the HPP at a market price with significant adjustments of parameters.
	Ncw=0.05 – baseline weight of cooling water utilization cost coefficient
Variable coefficient **N2**	**Estimated cooling water costs from NPPs**
1.1	High – it is possible to supply of cooling water from an external source (NPP) to the HPP with return water to NPP system. Minor adjustments of parameters.
1.0	Average - it is possible to continuously supply of cooling water from an external source (NPP) to the HPP at no recycling scheme or significant adjustments of parameters.

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0.9	Low – no use of cooling water from an external source (NPP).
	Ndw=0.04 – baseline weight of demi water utilization cost coefficient
Variable coefficient **N3**	**Estimated demi water costs from NPPs**
1.1	High – it is possible to supply of demi water from an external source (NPP) to the HPP. No required of demi water parameters adjustment.
1.0	Average - it is possible to continuously supply of demi water from an external source (NPP) to the HPP. Significant adjustment of parameters required.
0.9	Low – no possibility to supply of demi water from an external source (NPP).
	Noth=0.01 – baseline weight of non-crucial resources utilization cost coefficient
Variable coefficient **N4**	**Estimated non-crucial resources costs from NPPs**
1.1	High – it is possible to use of some of non-crucial resources/equipment from an external source (NPP) to the HPP at a special low price, with minor adjustments of parameters.
1.0	Average - it is possible to use of at least one of non-crucial resources/equipment from an external source (NPP) to the HPP.
0.9	Low – no possibility to use of at least one of non-crucial resources/equipment from an external source (NPP) to the HPP.
Variable coefficient **N5**	**Estimated reliability of NPP resource supply**
1.02	High – Number of units at NPP site are 3 or more (if NPPs crucial resources used)
1.0	Average - Number of units at NPP site are 2 (if NPPs crucial resources used). Or if any NPPs crucial resources used.
0.95	Low – Number of units at NPP is 1 (if NPPs crucial resources used)
Variable coefficient **N6**	**Estimated of NPP lifetime**
1.1	High - remaining lifetime of at least one NPP power unit after HPP commissioning more than 7 years (if NPPs crucial resources used).
1.0	Average - remaining lifetime of at least one NPP power unit after HPP commissioning more than 4 years (if NPPs crucial resources used). Or if any NPPs crucial resources used.
0.9	Low - remaining lifetime of all NPP power units after HPP commissioning less than 4 years (if NPPs crucial resources used).

4.2.2 Configuration costs - H.

The base weight of these costs (**HB**) is assumed to be 0.1 of LCOH.

H depends on the relative costs of NPP modifications and the difference of HPP configuration from the baseline.

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The costs of NPP modifications (including NPP licensing costs, additional NPP personnel costs) are inversely proportional to the costs of HPP configuration (and personnel). Therefore, modification costs are combined with HPP configuration costs and investigated as a common criterion. However, there may be different conditions that increase or decrease the total costs.

Therefore, specific conditions for modifications and specific conditions for the costs of additional (to the standard configuration) HPP equipment (stand-alone systems) are established for each NPP (model).

According to these model specific conditions, NPP modification (**Hm**) and HPP configuration (**Hc**) factors are selected.

The total relative cost of HPP configuration is **H=HB*Hm*Hc**.

The maximum range of **H** is (0.081-0.121).

Table 16 Assessment of NPP modifications/configuration costs.

Base weight of configuration costs, **HB**	**0.1**		
Costs of modifications		**HPP configuration**	
Hm	Status	**Hc**	Status
1.1	Very low - no need to modify NPP systems with basic resources. Minor licensing costs.	1.1	Very low - maximum resources from NPPs, no need to retrofit HPPs.
1.05	Low - minor modifications of NPP systems with basic resources are required, without affecting safety. Minor licensing costs.	1.05	Low - minor retrofitting of HPPs with autonomous resources (chillers, pressurized air, waste water system) is required.
1.0	Average - modifications of some NPP systems with safety impact or installation of additional equipment on several NPP systems. Licensing costs required.	1.0	Average - requires additional treatment of basic resources by HPP means (DW), regulation of temperature or pressure of cooling water, electrical equipment (transformers) at the HPP site.
0.95	High - significant modifications on all NPP systems providing the main HPP resources. Significant licensing costs.	0.95	High - retrofitting of the HPP with means of production of at least one of the basic resources (cooling water, DW, electricity).
0.9	Very high - impossibility to modify at least one of the main resources without significant impact on safety or reliability of NPP operation. Significant licensing costs.	0.9	Very high - several of the key resources are not available from the NPP and must be produced at the HPP.

4.2.3 Logistics costs- L.

The base weight of these costs (**LB**)- is assumed to be 0.2 of LCOH.

L depends on relative costs of construction and maintenance of intermediate hydrogen storage and costs of hydrogen transportation from HPP to storage and from storage to consumers.

For each NPP (model) specific conditions of hydrogen storage location and means of hydrogen delivery from HPP are established. Closer location of HPP to NPPs reduces the attractiveness of the model taking into account NPP safety during transportation and storage of large volumes of hydrogen near NPP facilities. However, transportation and maintenance can reduce costs for such models. Conversely, remote location of storage simplifies safety and HPP licensing, but increases the cost of site logistics. These factors are taken into account by determining the local storage factor - **Ls**.

Potential hydrogen consumers, their consumption volumes, remoteness from HPP storage, proposed methods of hydrogen delivery, and the impact of customs regulations are also assessed. These factors are taken into account by determining the consumer coefficient - **Lc**.

Total costs of initial resource supply - **L=LB*Ls*Lc.**

The maximum range of **L**- (0.162-0.242).

Table 17 Assessment of logistics costs.

Base weight of logistics costs, **LB**	**0.2**		
Local storage coefficient		**Consumer coefficient**	
Ls	Status	**Lc**	Status
1.1	Very high - there are storage facilities that can be used for new HPP. Low costs of hydrogen delivery to the storage are required. Distance from storage and transportation routes to NPP structures and communications is more than 2 km.	1.1	Very high - there are pipelines to transport hydrogen to major consumer areas directly from the HPP or storage site. Or low costs are required to transport hydrogen from the storage site.
1.05	High - the storage facility and transportation routes can be located at a distance of more than 2 km from NPP structures and communications. Low costs of hydrogen delivery to the storage are required.	1.05	The hydrogen demand is confirmed to be more than 2 times the capacity of the HPP.
1.0	Average - HPP offsite. Storage location and hydrogen transportation routes from HPP are not defined.	1.0	Consumers and HPP are located within one economic zone/country, and the hydrogen demand is not confirmed to be more than 2 times the capacity of the HPP.
0.95	Low - HPP is located at the NPP site.	0.95	Satisfactory conditions of hydrogen delivery to potential consumers are determined. Consumers and HPP are located within one economic zone/country.

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0.9	Very low - HPP is located at the NPP site. Storage location requires additional NPP safety measures or significant costs are required for hydrogen transportation from HPP to storage.	0.9	Consumers and HPP are not located within one economic zone/country, or The hydrogen demand is not confirmed to be more than the capacity of the HPP.

Table 18 Decision matrix components range

		Base	Min	Max
N	Costs of NPP resources	**0.7**	0.513	0.864
H	HPP configuration costs	**0.1**	0.081	0.121
L	Logistics costs	**0.2**	0.162	0.242

Table 19 Decision matrix components structure

		Base	Range, Min-Max		Average value			
		NB	N		Nel	Ncw	Ndw	Noth
N	Costs of NPP resources	**0.7**	0.513	0.864	0.63	0.035	0.028	0.007
H	HPP configuration costs	**HB**	H		Hm*Hc = (0.1)			
		0.1	0.081	0.121				
L	Logistics costs	**HL**	L		Ls*Lc = (0.2)			
		0.2	0.162	0.242				
Summary score		1.0	0.756	1.295				

Criteria	EL	CW	DW	Other	NPP modific/licens. -HPP configur.	Storage	Transport/ customers
Structure, % LCOH	63	3.5	2.8	0.7	10	10	10

The decision matrix was updated based on the results of Tasks 2, 3, 4, and as well discussions with experts in frame of Task 5.

The matrix considers, with appropriate weights, the unique conditions for the models in the following criteria:

1. Electricity prices;
2. Cooling water prices;
3. Demi water prices;
4. Costs of other resources from NPPs (nitrogen, compressed air, tap water, chillers, sewage);
5. The multi-unit capacity of NPPs (reliability of resource supply);
6. Remaining lifetime of NPP (duration of resource supply and country policy);

7. Costs of NPP system modifications and licensing;

8. Costs of additional HPP equipment and maintenance;

9. Costs of safe location of intermediate hydrogen storage and safe transportation of hydrogen from HPP;

10. Costs of hydrogen transportation to potential consumers.

A very important component for evaluating the candidates for the location of an NPP-HPP- couple is the national policy in the field of nuclear energy. There is no clear criterion for assessing the risks of changing this policy. However, it can be noted that if the policy is changed towards the abandonment of NPPs, its implementation is carried out sequentially. If the relevant decision is made, it is likely that the operating NPPs will be decommissioned at the end of their lifetime. Therefore, to evaluate this criterion, the lifetime of the candidate NPP is considered in the decision matrix. The residual lifetime of NPPs (coefficient N6) is an indirect indicator of the realization of the state policy in case of abandonment of nuclear energy.

Table 20 Decision matrix

Model	NB (0.7)						HB (0.1)		LB (0.2)		**Total**
	EL	CW	DW	Other	T5	T6	Hm	Hc	Ls	Lc	
NPP1											
NPP2											
NPP3											
NPP4											
NPP5											
…											
	Nel*N1	Ncw*N2	Ndw*N3	Noth*N4	N5	N6	Hm	Hc	Ls	Lc	

5 Overall assessment of the candidate site (NPP)

The overall score is determined from the sum of the points for all criteria. However, the weight (contribution) of each criterion is not equal due to the different costs of each aspect of hydrogen production.

The total score of the candidate site (NPP) will be determined as the sum of the points of all criteria, considering correction factors:

A(NPP)= NB*(Nel*N1+Ncw*N2+Ndw*N3+Noth*N4)*N5*N6+HB*Hm*Hc+LB*Ls*Lc.

or,

A(NPP) = (0.63*N1+0.035*N2+0.028*N3+0.007*N4)*N5*N6+0.1*Hm*Hc+0.2*Ls*Lc.

By comparing the points of the different candidate sites, the most suitable options (or pilot site-A NPP) are identified by the highest sum of points, A(NPP).

If necessary, in case the aggregate scores of two or more candidate sites are close, a more detailed iteration of the criteria evaluations may be conducted, considering, for example, the availability of non-core resources.

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6 Conclusions

The decision matrix has been designed to cover all aspects relevant to the selection of a suitable site. The outputs of the WP reports already produced under the NPHyCo project were used as input for the matrix. The functionality of the decision matrix was tested and debugged using data already obtained from candidate NPPs.

The decision matrix is used by already operating candidate NPPs to help the candidate find the optimal HPP scenario in each location and to select the optimal technology. But the final decision of the optimal scenario and technology is up to each candidate. In the framework of the NPHyCo project, this matrix is used to compare individual candidate NPPs for HPP siting.

The matrix does not serve as a decision element from which to determine whether a project is viable for a given location and thus cannot be used to decide whether to build the project at a given location. The matrix can only help to select the optimal scenario, technology for a given site. Based on the matrix, the NPHyCo project will select the most suitable candidate site from among the European NPPs that have provided the necessary information . For this candidate NPP, a project will then be prepared based on which it will be possible to calculate the profitability of the project.

For NPPs that will consider building an HPP at their site in the future, the matrix can serve as a basis for collecting the necessary input data and for help with selecting the optimal cogeneration scenario between the NPP and HPP. Finally, it can be used for comparison with plants that have been involved in the NPHyCo project.

In the next phases of the WP5 package, all the collected data will be analysed and calculations for the candidate NPPs will be performed. Several calculations will be performed for each candidate NPP to determine the best scenario for the site. The individual scenarios of each NPP will then be compared with the other candidate NPPs.

If there will be a requirement to apply the matrix to non-LTE technologies, the individual coefficients will need to be adjusted to match the technology requirements (e.g. HTSE), as is described in chapter 4.1.

7 Bibliography

[1] Deliverable 3.2

[2] Deliverable 3.1

[3] Deliverable 4.2

[4] Deliverable 6.3

[5] Deliverable 1.2

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