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WP 1	**Demonstration requirements and specifications**		

D1.1 – End User spec & document agreed with users, including KPI for two case study sites

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		For Review by Coordinator
	X	**Submitted**
Version:	V1	
Abstract	The deliverable is a *living* document and in its first version reports on the key performance indicators (KPIs) identified to measure the performance of the GeoSmart system.	

REVISION HISTORY

Version	Date	Main Authors/Contributors	Description of changes

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* Dissemination level security:

PU – Public (e.g. on website, for publication etc.) / **PP** – Restricted to other programme participants (incl. Commission services) /

RE – Restricted to a group specified by the consortium (incl. Commission services) / **CO** – confidential, only for members of the consortium (incl. Commission services)

Document: D1.1 End user spec and document agreed with users, including KPIs for two case study sites

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Version: V1

Date: 2 April 2020

CONTENTS

1 EXECUTIVE SUMMARY

The current deliverable reports on the key performance indicators (KPIs) identified to evaluate the functionalities of the GeoSmart system. This is a working document and in its *first* version provides a distinctive starting point for the consortium to ensure assessment of performance outcome of the project: a) at sub-system level; b) for the overall GeoSmart system and c) for the knowledgebase software tool. The document outlines the concept, methodology, definitions and calculation methods (as applicable) to monitor the performance of the systems in the demonstration sites.

The KPIs identified (as below) will be continuously monitored and updated (as and when needed) to ensure that they help monitor the achievement of the strategic goals across all project activities.

2 OBJECTIVES MET

The deliverable contributes towards the following work package objectives:

- To develop the detailed key performance indicators for the project success, and for the detailed final designs for the demonstration systems for each demo site. These will be maintained as working documents, updated throughout the project as knowledge and situations change, to ensure that all partners are working from the same set of success criteria.

3 KPI DESCRIPTION

3.1 Methodology

Key Performance Indicators are a set of quantifiable values used to demonstrate performance of the proposed technological solution. The GeoSmart consortium intends to use these KPIs at multiple levels to measure the performance outcome. The relevance of the KPIs has been established by use of the SMART (**S**pecific, **M**easurable, **A**ttainable, **R**elevant and **T**ime-bound) criteria. A template was prepared comprising the main elements that needed to be developed for each KPI (see Table 1).

Table 1. Template for capturing KPI

Rationale Reasoning for use of the indicator and how it can be used to demonstrate the performance of the system. The objectives that would be targeted as a measurement for improvement.	**Target** Measuring improvement compared with the current state of the art.
Source Equations/formulas used to calculate, monitor and measure the KPI	**Method of measuring** Specific conditions under which the KPI will be measured or needs to measured

The template was completed by all work package (WP) leaders and discussions were held to clarify the definitions of the KPIs identified, to complete missing information, and to ensure consistent terminology across all WPs. Two workshops were conducted in the first six months of the project to establish and finalise KPIs for the two demonstration sites — Zorlu (Figure 1) and Balmatt (Figure 2) respectively.

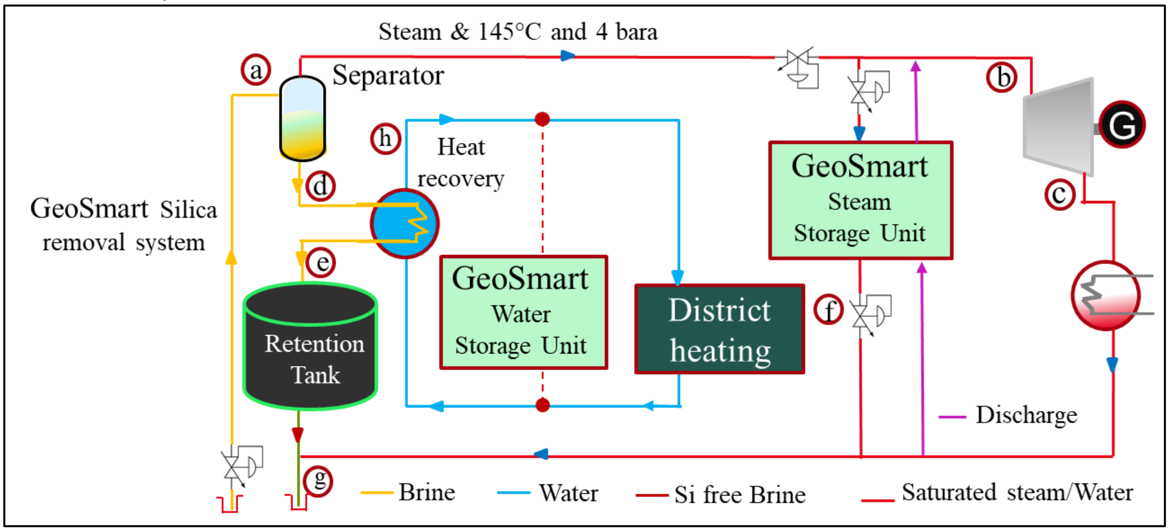

Figure 1. Description of proposed system (Zorlu)

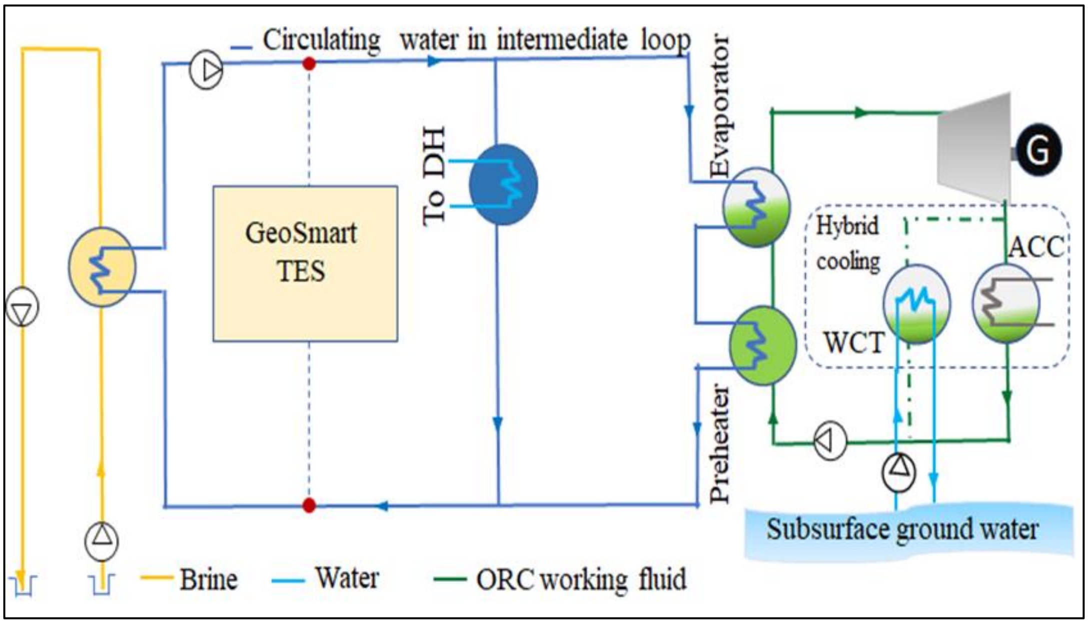

Figure 2. Description of proposed system (Balmatt)

The KPIs have been identified at the following levels:

- **KPIs at global level**

  Overall targets defined to characterise the success of the technology developed for optimisation and to demonstrate innovations to improve the flexibility and efficiency of geothermal heat and power systems.

- **KPIs at technology level**

  These are specific KPIs defined to characterise the innovative technologies developed in the project. The definitions of these KPIs are important to demonstrate the desired level of performance outcome at a sub-system level:

  - Thermal storage which includes the thermal storage units at Zorlu and Balmatt, hybrid cooling with ATES (Aquifer Thermal Energy Storage at Balmatt and the brine storage system at Zorlu;
  - Heat exchanger system at Zorlu;
  - Retention tank at Zorlu;
  - Flexible Organic Rankine Cycle (ORC) at Balmatt;
  - The GeoSmart simulator suite.

- **Non-technical KPIs**

  These include the environmental and general KPIs at business and dissemination level[2].

Categorisation of KPIs

GeoSmart KPIs have been categorised to effectively express one or more aspects of performance assessment. Table 2 gives an overview of the KPI categories used in the project.

Table 2 Overview of the KPI categories in GeoSmart

KPI category	Description
Technical	• Thermal storage efficiency • Flexibility of ORC • Retention tank efficiency
Economic	• Levelised cost of energy (LCOE) • Levelised cost of heat (LCOH) • Profit from energy sale
Environmental	• Reduction in consumption of fossil fuels

[2] The dissemination KPIs will be included in D9.7 A dissemination plan due M10.

3.2 Global KPI (for each site)

Type	Description	KPI	Remarks
Financial	**Cost efficiency in LCOE** calculated as % increase or decrease compared with the initial configuration	$LCOE = \frac{LCOE\ Geosmart - LCOE\ Initial}{LCOE\ initial}.100$	LCOE- Levelised cost of energy
	Cycle efficiency calculated as % increase or decrease compared with the initial configuration	$Pnet = Pgross - Psubsystem$ $CE = \frac{Pnet\ geosmart - Pnet\ initial}{Pnet\ initial}.100$	Pgross is the power produced by the plant Psubsystem is the power consumed by the subsystems of the plant
	Process efficiency improvement (PEIE) in **%** for electricity production	$PEIE = \frac{Ecum,process,a - Ecum,process,ini}{Ecum,process,ini}.100$	Ecum, process,ini (kWh) is the electricity production for a given period of time for the process in its initial state, for instance during one year. Ecum, process,a is the electricity production for the same period of time when the component A is added in the process.

Type	Description	KPI	Remarks
Financial (continued)	**Process efficiency improvement (PEIH)** in % for district heating production	$PEIE = \frac{Ecum, process, a - Ecum, process, ini}{Ecum, process, ini} .100$	Ecum, process,ini (kWh) is the heat production for a given period of time for the process in its initial state, for instance during on year. Ecum,process,a is the heat production for the same period of time when the component A is added in the process.
	Improved Response time (IRS) as a % compared with the initial response time	$RS = t\ Output - t\ input$ $IRS = \frac{RS\ geomsmart - RSinitial}{RSinitial} .100$	t input is the time of request from an operator t output is the time at which electricity or heat production is delivered to the grid RS time between inputting the demands into a settled system and achieving a settle system at the demanded new output setting
	Increased revenue in % (REV)	$REV = \frac{(NET\ Revenue\ Geosmart - NET\ Revenue\ Initial\ over\ period\ t)}{NET\ Revenue\ Initial\ over\ period\ t} .100$	Revenue in local currency Case 1 : net revenue from electricity delivery Case 2: net revenue from heat delivery Case 3: net revenue from electricity and heat delivery
	Net present value	$NPV = \Sigma \frac{(Cash\ Flow)}{(1+r)\hat{}i}$	r: discount rate i: time period
	Internal rate of return (IRR)	$NPV = 0 = \Sigma \frac{(Cash\ Flow)}{(1+IRR)\hat{}i}$	IRR is the discount rate for which the NPV is zero.

Type	Description	KPI	Remarks
Environmental	**Reduced use of fossil fuel (FF) in %**	FF$= \frac{Gas\ consumed\ initial\ \ over\ period\ t - Gas\ consumed\ geosmart}{Gas\ consumed\ initial\ over\ period\ t}.100$	

3.3 Thermal Storage

Type	Description	KPI	Remarks
Technical	**Heat storage density (HSD) in kWh/m3**	$HSD = \frac{Edesign}{Volume}$	Edesign (kWh) is the energy calculated after a full charge at nominal conditions and new materials after cycling stabilisation . Volume (m3) is the volume of the module including metallic parts (not only storage material). We can calculate 3 volumes: 1- The module (reference case) 2- The module with insulation 3- The module with insulation + auxiliaries
	Heat storage design ratio in **%** - This ratio gives the difference between the real stored energy at nominal conditions of full charge and the design energy. This factor can vary during time because of material aging, for example phase change materials (PCMs). It should be done at year 0 (gives then the uncertainties of design model), then every year.	$HSDR = \frac{Echarge, measured}{Echarge, design}.100$	Echarge,measured (kWh) is the energy stored during a full charge at nominal conditions with new or aged materials after cycling stabilisation. Echarge,design (kWh) is the energy calculated during a full charge at nominal conditions and new materials after cycling stabilisation.

Type	Description	KPI	Remarks
	Heat storage capacity ratio (HSCR) in **% -** This ratio compares the stored energy at nominal conditions and the maximum energy that could be stored (for instance PCM melted 100% or sensible material fully charged) in a stable state (after a few thermal cycles).	$HSCR = \frac{Echarge, measured}{Echarge, max}$	Echarge,max in kWh is the maximum energy that could be stored in the module (sensible and latent). For PCM module includes PCM and metallic parts.
Technical (continued)	**Response Time in Seconds (RS)** – Measured as difference between request for extra steam from steam storage to time for extra energy production	$RS = t\ Output - t\ input$	t input is the time of request to the storage system t output is the time at which heat production increases RS time between inputting the demands into a settled system and achieving a settle system at the demanded new output setting
Financial	**Heat storage cost (HSC) in €/kWh** This value is given by the cost model and/or the true manufacture cost of modules.	$HSC = \frac{Cost}{Echarge}$	Cost is the cost (€) of the module ready for operation (including site preparation, auxiliaries, measures, insulation, control….etc) provided by a model (during preliminaries studies) or by real costs (at the end of the project). Echarge is the energy (kWh) charged in the module in nominal conditions. It can be the design energy (during preliminary studies) or the measured energy (at the end of the project).

Type	Description	KPI	Remarks
	Cumulative stored energy or number of full cycles (NFC) of storage equivalence The cumulative stored energy Ecum (kWh) is the energy stored in the module during a given period of time (day/month/year). If the geothermal site has an annual cycle, it is better to do the calculation on a one-year period. This energy cumulates full and partial charges. To ease the techno-economic studies, it is practical to calculate the number of full charges/discharges equivalence (kWh/kWh)	$NFC = \frac{Ecum}{Echarge}$	Echarge is the energy (kWh) charged in the module in nominal conditions. It can be the design energy (during preliminary studies) or the measured energy (at the end of the project).

3.4 Control strategy and system for flexible ORC

Type	**Description**	**KPI**	
Technical	**Outlet temperature control ΔT_{out}** The temperature difference between the setpoint of the outlet temperature of the hot water on the ORC and the real valueof	$\Delta T = abs(T_{out,setpoint} - T_{out,real})$	$T_{out,setpoint}$ is the desired outlet temperature (°C) $T_{out,real}$ is the real outlet temperature (°C)
	Response Time in Seconds (RS) – Measured as difference between request for electricity production to time for electricity production	$RS = t\ Output - t\ input$	t input is the time of request to the ORC t output is the time at which electricity production increases

3.5 Development of scaling reduction system

Type	**Description**	**KPI**	
Technical	**[%] efficiency of Silica Removal System SRS**	$SRS = \frac{SIO2\ input - SIO2\ output}{SIO2\ input} .100$	Residual SI02 should not cause scaling effect in down stream piping and reinjection well
Technical	**[%] efficiency of Scale Suppression System SSS** Scaling A = without SSS Scaling B = with SSS	$SSS = \frac{SIO2\ scaling\ A - SIO2\ scaling\ B}{SIO2\ scaling\ A} .100$	Scaling should not occur in down stream piping and reinjection well therefore SSS needs to be near to 100% as much as possible

3.6 Scaling system Heat Exchanger

Type	Description	KPI	
Technical	The 2 following KPIs indicate the distance between design and reality; one for the heat power exchanged (HEPDR in %) and the second one for the pressure drop (HEDPDR in %).	$HEPDR = \frac{P_{heatexchanger,measured}}{P_{heatexchanger,design}}.100$ $HEDPDR = \frac{DP_{heatexchanger,measured}}{DP_{heatexchanger,design}}.100$	$P_{heatexchanger,measured}$ is the power (W) measured in the heat exchanger in the nominal conditions (clean or after some scaling) $P_{heatexchanger,design}$ is the power (W) calculated in the heat exchanger in the nominal conditions (clean) $DP_{heatexchanger,measured}$ is the pressure drop (Pa) measured in the heat exchanger in the nominal conditions on brine side (clean or after some scaling) $DP_{heatexchanger,design}$ is the pressure drop (Pa) calculated in the heat exchanger in the nominal conditions on brine side (clean)
Technical	The 2 following KPIs indicate the increase of heat recovery from the brine at the end of the project: "Gain" in re-injection temperature without significant scaling (DT_{output} in °C, NB this value is negative) . Efficiency of brine heat recovery compared to a maximal target of the GeoSmart project (BHRE in %)	$\Delta T_{output} = T_{ouput,Geosmart} - T_{output,initial}$ $BHRE = \frac{T_{output,GeoSmart} - T_{output,initial}}{T_{output,min} - T_{output,initial}} * 100$	$T_{output,initial}$ is the re-injection temperature (104°C) Toutput,min is the target minimal temperature (50°C) $T_{output,GeoSmart}$ is the measured reinjection temperature without significant scaling Significant scaling must be defined by the site owner. For instance one cleaning per year/month/week/day.
Technical	Effectiveness in terms of heat exchange The effectiveness of a heat exchanger represents the ratio between the thermal power actually exchanged and the maximum power theoretically exchangeable with the same inlet	$HEE = \frac{\phi_{real}}{\phi_{max}} * 100$	$\dot{m}$ is the mass flowrate on hot or cold side(kg/s) Cp is the fluid heat capacity (J/kg/K) on hot or cold side T is the temperature (K or °C) respectively on hot or cold side and inlet or outlet.

	conditions (same fluids, same flow rates and inlet temperatures) (HEE in %). This criteria is very important when it is important to minimize the pinch DT of the heat-exchanger ($T_{hot,inlet}$-$T_{cold,outlet}$ or $T_{hot,outlet}$-$T_{cold,inlet}$) but is not very important for Zorlu site. Therefore we define another KPI for the scaling heat-exchanger related to the residence time that is more relevant: Scaling risk in the heat-exchanger: ratio between the residence time inside the heat-exchanger and the maximal allowed residence time (SR in %)	$HEE = \frac{(\dot{m}c_p)_{hot}(T_{hot\ inlet} - T_{hot\ outlet})}{(\dot{m}c_p)_{min}(T_{hot\ inlet} - T_{cold\ inlet})} * 100$ $SR = \frac{t_{heat-exchanger}}{t_{max,kinetics}}*100$	Hot side is brine and cold side is water. The exact properties of the brine must be defined. $t_{heat-exchanger}$ is the residence time in second in the heat-exchanger $t_{max,kinetics}$ is the maximal time before significant scaling at the outlet temperature, calculated from the brine content and kinetics model

4 NEXT STEPS

The current document is a *living* document that has been used to identify KPIs at the technical and global level and will be updated as the project progress. An updated version of the document, listing the final KPIs for the two case studies **D1.7 Final document of the end user spec document agreed with the users including KPIs for two case studies** will be submitted in M45.

5 REFRENCES

- Evidence Gathering: Thermal Energy Storage (TES) Technologies, Department for Business, Energy and Industrial strategy.
- Hyungsul Moon and Sadiq J. Zarrouk. Efficiency of geothermal power plants: a worldwide review, New Zealand Geothermal Workshop 2012 Proceedings 19 - 21 November 2012.