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Theistareykir Geothermal Power Plant - Challenges in Project Management During Design and Construction

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ABSTRACT

The geothermal area at Theistareykir in north east of Iceland has great potential for geothermal utilization, with an estimated capacity of up to 200 MW_e. Preparation work and research on the sustainable utilization of geothermal energy at Theistareykir began in 1999 by an association founded by local municipalities and regional utility companies, later merged into the National Power Company of Iceland, Landsvirkjun. The objective was to harness the geothermal resource in a sustainable way. In 2011 a breakthrough milestone was achieved in the project when Landsvirkjun signed a contract with local consulting company for tender and detail design Theistareykir project. The following years preparations works were carried out at site. In 2015 a contract for turbine, generator and cold end was signed and construction at site started. From 2016 production drilling continued for 90 MW_e. In end of 2017 unit 1 started commercial operation and unit 2 started commercial operation in spring of 2018. Today the Theistareykir geothermal power plant operates at 90 MW_e.

This paper summarizes the challenges and solutions the Landsvirkjun project team went through during the design, planning and construction of Theistareykir, 90 MW_e, geothermal power plant in NE-Iceland, such has Landsvirkjun's approach to project management as a responsible owner of the project and experienced operator of 16 Power Plants, break-down of the construction works in separate tendering processes, how a comprehensive project risk assessment and communication schedule for all stake holders was conducted and finally but not least Landsvirkjun's approach to health safety and environmental issues during the construction.

1. INTRODUCTION

The geothermal area at Theistareykir in north east of Iceland has great potential for geothermal utilization, with an estimated capacity of up to 200 MW_e. The Theistareykir geothermal field is a part of the north-east highlands of Iceland. The area is located 27 km south of town of Húsavík and some 25 km north of Lake Mývatn, see figure 1.

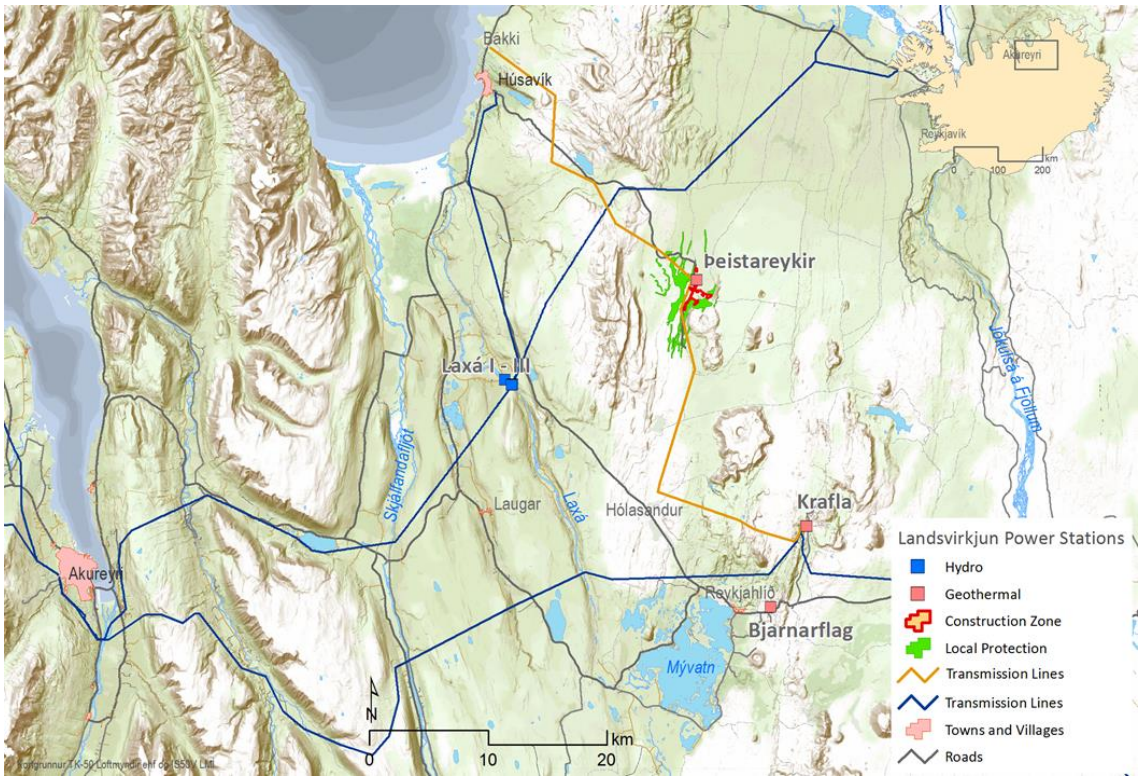

Figure 1: Map showing part of north-east Iceland and the location of Theistareykir area

Exploration of the area started as early as in the nineteen-seventies. Preparation work and research on the sustainable utilization of geothermal energy at Theistareykir began in 1999 by an association founded by local municipalities and regional utility companies, later merged into the National Power Company of Iceland, Landsvirkjun. In addition to planning, licensing and environmental impact assessment, the first 15 years were used for explorational drilling to confirm potential steam availability, stakeholder management with consultation to landowners and users of the planned construction area as well as a definition of vegetation reclamation program.

At project launching in April 2015 nine steam wells with total of 58 MW_e capacity had been drilled. The construction of the power plant was carried out from spring 2015 and late 2017 the first 45 MW_e production started followed by additional 45 MW_e in spring of 2018. Since middle of 2018 the Theistareykir geothermal power plant has been operating at 90 MW_e.

This paper summarizes in brief the history of the Theistareykir geothermal power plant project, Landsvirkjun's approach at project management for the construction and the challenges and solutions the project team went through during the planning, design and construction of power plant.

2. THEISTAREYKIR AT GLANCE

2.1 Construction history

The geothermal area at Theistareykir is registered in the Icelandic Nature Conservation Register as the fumaroles located there are very active. Stóravítishraun lava field is approximately 525 km^2 runs through the area. The area is considered to be of historical relevance with over 50 registered heritage sites. It is uninhabited but has a ramblers' hut and is used as a grazing common for 5,000 sheep every summer.

Surface exploration in the Theistareykir area started in the nineteen-seventies and continued intermittently to the mid nineteen-eighties, Gíslason et al. (1984). In the late nineteen-nineties interest in the field was renewed, this time the project was initiated by local residents who wanted to explore how they could harness the geothermal energy in the area to create employment opportunities in the municipality. Preparation work and research on the sustainable utilization of geothermal energy at Theistareykir began with the establishment of Theistareykir Ltd. in 1999. The association was founded by Húsavík Energy, Akureyri Electricity Utility and Akureyri Heating and Water Utilities, Adaldælahreppur County and Reykdælahreppur County, Knútsson et al. (2018). In the beginning of 2014 Theistareykir Ltd. merged with Landsvirkjun.

Exploration drilling started in 2002 with the completion of well ThG-01, a vertical well reaching 1953 m below the surface, Gautason et al. (2010). Exploration drilling continued intermittently throughout 2013 when the ninth exploration well was drilled. The exploration wells provided data from a ~4 to 5 km^3 volume of the geothermal reservoir. To date the highest bedrock temperatures recorded in the area close to 380°C. This is one of the highest temperatures recorded in a production well in Iceland so far. The first phase of exploration drilling in the Theistareykir area confirmed that the area has great potential for electrical production using conventional methods, Gautason et al. (2010). By the time the exploration drilling finished the land utilization and protection plan for the area and the regional plan had been developed. In addition, the Environmental Impact Assessment, EIA, had been published see Knútsson et al., (2018). The results of the exploration drilling and the result of the EIA provided confidence for decision of starting construction of 90 MWe power plant at the Theistareykir site.

In 2011 a breakthrough milestone was achieved in the project when Landsvirkjun signed a contract with Mannvit-Verkís for tender and detail design Theistareykir project. The following years preparations works were carried out at site. The preparation works included construction of an access road, groundwork on the powerhouse foundation, the construction of water facilities, electrical distribution system to the site and within the site and other infrastructure. Early 2015 a contract for turbine, generator and cold end with the consortium of Fuji Electric and Balcke-Dürr was signed. In April 2015 the formal decision to start construction for geothermal power plant at Theistareykir was made and in May 2015 civil works and steam supply system started. Civil contractor, LNS Saga, now Munck Íslandi, carried out all civil works and erection of steam supply system, Knútsson et al. (2018).

Construction continued throughout 2016. In addition, geothermal drilling started again in the area. As with all exploration drilling the drilling contractor was Jarðboranir. From 2016 to 2017 nine additional production wells were drilled. Installation of mechanical and electrical parts started beginning of 2017. Fuji Electric and Balcke-Dürr provided turbine, generator and cold end, ABB provided the control system, Tamini provided the transformers and Rafeyri, local electrical contractor, installed all Station Services and Auxiliary Systems. Commissioning of Unit 1 started in the fall of 2017 and in beginning of December 2017 commercial production of 45 MW_e started at Theistareykir. Commissioning of Unit 2 started in February 2018 and middle of April 2018 Unit 2 started commercial production. By that time the Theistareykir geothermal power plant produced 90 MW_e, Knútsson et al. (2018).

Both units have proven to fulfill the requirements made according to contracts. The performance of the units and the supply systems in handling unexpected events has met the requirements, especially has the performance of the units to participate actively in regulating the grid frequency been better than expected, Hardarson et al. (2018). Figure 2 shows Theistareykir Geothermal Power Plant in full operation in winter of 2018/2019.

Figure 2: Theistareykir Geothermal Power Plant in full operation in winter of 2018/2019

2.2 Conceptual design and progress flow diagram

One of the main design criteria for the Theistareykir geothermal power plant is that the plant shall be robust and based on proven design. That is, the power plant should be based on standard technology. The reason for this is the location of the power plant, in the north-east Iceland highlands where services can be challenging, especially during winter season. To fulfill this requirement the turbines, generators and cold end were chosen to be 45 MW_e single flow single flash. This type of turbine is common in the Icelandic national grid. This results in that all setup for buildings and steam supply system is built up for 45 MW_e modules, Knútsson et. al. (2018). As of now the Theistareykir power plant operates two modules, total production of 90 MW_e. The plant can potentially be expanded in a modular way up to 200 MW_e by adding new drilling sites to the power plant production area and thereby expanding the utilization of the geothermal field.

Based on robust and proven design the progress flow diagram for the geothermal power plant was defined as seen in figure 3.

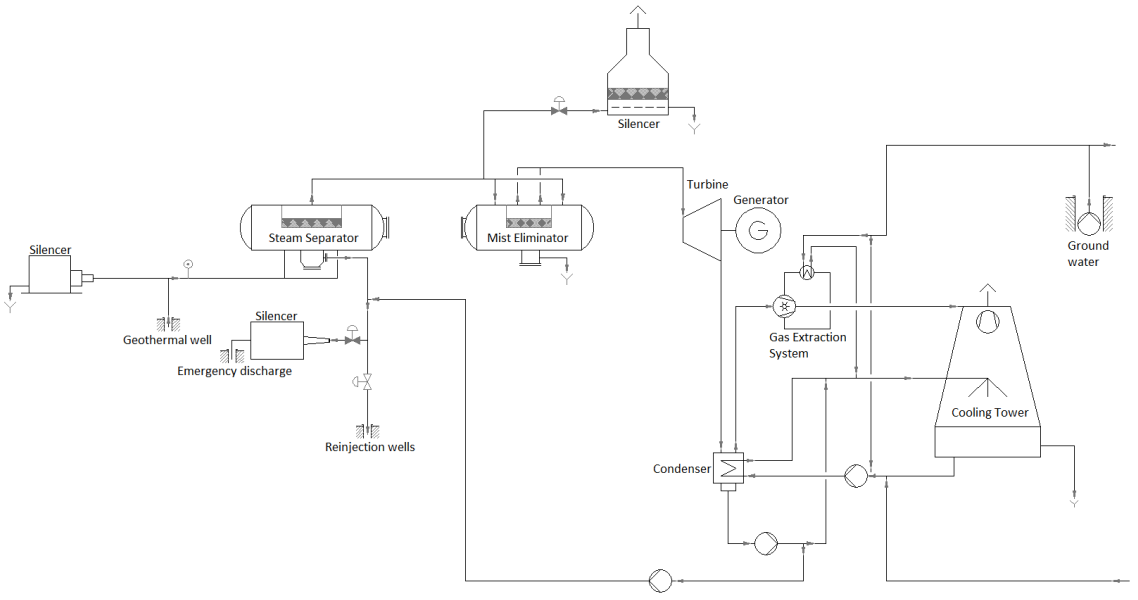

Figure 3: Simplified progress flow diagram for Theistareykir Geothermal Power Plant

The two-phase geothermal fluid flows from the production wells through steam gathering pipelines to a steam separator. The steam flows to the mist eliminator while the separated water is mixed with condensed water and is re-injected into the reservoir. In case of regulation or a trip is needed the steam can all be exhausted through silencer.

The steam flowing through the turbine, which is designed as a single cylinder condensing with twelve reaction type stages. The generator is directly shaft coupled to the turbine. From the turbine the steam enters a closed type shell and tube condenser and condensates. The condensate water is either used for mixing with the separated water or used as make-up water in the cooling water circulation.

The steam contains traces of non-condensable gases up to 0.2%. Geothermal gases are extracted from the condenser with hybrid system of steam ejectors and vacuum pumps to prevent the accumulation of geothermal gases. The geothermal gases are then vented to the atmosphere, above the cooling tower's fans. For more details on the progress flow see Hardarson et al. (2018) and Hardarson et al. (2920).

3 THEISTAREYKIR PROJECT

Landsvirkjun has a long history in Iceland in preparing and executing megaprojects related to the construction of power plants. Project preparation and execution practices based on the corporate vision and clear project objectives have been developed on all of the project aspects, including costs, schedules, quality, scope, HSE, environmental impact, sustainability and stakeholder management.

Landsvirkjun's corporate vision as an energy producer and leader in utilizing its renewable energy sources in a sustainable manner, with minimum environmental impact, is reflected in the project's objectives prioritizing the sustainable harnessing of the geothermal area as its core objective. Decades of structured geological research and more than 15 years of exploration drilling during the project's preparation phase in order to estimate and evaluate the energy resource, set the boundaries of the sustainable definition of the project´s scope.

Based on Landsvirkjun's long history and experience in project management for large power projects and international standards for project management, Sedlmayer, M. et al (2015), Landsvirkjun established a Project Team under control of Project Director.

4 PROJECT MANAGMENT

Landsvirkjun is a state-owned company whose role it is to consistently maximize the potential yield and value of the natural resources it has been entrusted with, in a sustainable, responsible and efficient manner. Landsvirkjun has established an ambitious strategy on corporate social responsibility, which states that it is the company's role to create value, to respect and protect natural resources and the environment and to share its expertise to effectively contribute to society

Preparation work and research on the sustainable utilization of geothermal energy at Theistareykir began in 1999 by an association founded by local municipalities and regional utility companies. The association later merged into Landsvirkjun. The objective was to harness the geothermal resource in a sustainable way for the benefit of the Municipalities in North East Iceland, Knútsson et al., (2018)

4.1 Perspective

Landsvirkjun project strategy reflects its objectives in being a responsible owner and developer of power plant projects in Iceland's sensitive environment. Strategies on safe construction, effective scope and cost management with a judicious construction time are the basis of all its construction activities.

Implementing the strategy on the sustainable utilization of energy resources, with which the company is entrusted, is achieved by the monitoring of selected critical reservoir conditions and physical measurements of selected parameters for reservoir control, simulations and the development of simulation models and monitoring plans. The information and simulations are used to further increase the scientific knowledge of high temperature geothermal areas, their physical reactions to utilization and possibilities for the future benefit of the utilization of green energy from high temperature fields around the world. Participation in a European Research Program on Gravimetry is a pioneering activity to extend current monitoring and research methods regarding geothermal energy reservoirs.

Implementing strategy towards environmental objectives is included in the project´s Environmental Monitoring Plan where mitigation and monitoring for identified environmental aspects are outlined. Revision is carried out on a regular basis.

The location of Theistareykir geotherm power plant and its connection to a weak power grid in North-East Iceland called for the setting of functional objectives to meet the requirements of the transmission grid operator, as well as meeting the quality demands that the energy intensive users have towards the plant´s electrical power generation. Strict requirements were therefore set on regulations of frequency, load and voltage of the electricity generating units. Requirements for high reliability also called for specific measures for redundant functionality within the power plant, see Hardarson et al 2018 and Heimisson et al 2020.

Examples of project objectives on cost, schedule, scope and other general project aspects are listed in Table 1. Objectives for the scheduling of the project´s phases and milestones inside each phase are a part of the overall project schedule. This includes, but is not limited to, the scheduling of design sections, tendering and contracting, procurement and contract kick-off, design review and follow-up, as well as the training of operation staff and the plant´s handing over for commercial operation.

Table 1: Examples of key project objective and strategy for obtaining them

Task	Key project objective	Strategy to obtain objective
Cost	To develop realistic cost estimate by taking notice of best practises in energy utilization and respecting the corperate objectives. To complete the project with AC according to BAC.	Budgeting at preparation phase for company board approval. Benchmark project cost compared to sector $/MWh. Formal approval of base cost-estimate by project steering group or company executive management for the project after tendering major contracts. Regular cost reviews. Effective scope management
Time	To develop a project schedule which inlcudes due care for sustainable harvesting of the geothermal resources, minimizes construction risk due to harch arctic winter conditions in the highlands of North-east Iceland and allows ample working conditions for safe construction operations. To deliver project on time according to contracts.	Schedule management are of great importance to ensure safe and cost effective construction activites. Close cooperation with contractors to actively monitor and mitigate project schedule risks. Active monitoring and control on different project phases and key-milstones. Management of project master-plan and Critical Path activities. Management of individual contracts and effective coordination of construction activities.
Safety	Safety of its construction workers is of utmost importance for Landsvirkjun and the company therefore maintains a Zero accident policy.	Based on its strong believes that all construction activities can be done in a safe manner, the company continuously strives for improved safey culture of its own employees as well as all project participants of its contractors and subcontractors. All employees should be familiar with the content of the zero accident policy and safe work conditions. All employees gain required HSE training.
Licencing/planni	Construction in harmony with legal requirements.	All licences granted before start of construction. Monitor possible changes regarding rules and regulations.

4.1.1 Governance, structures and processes

The project was sponsored by the Executive Vice President of the Landsvirkjun Project Construction and Planning division and managed by the Project Director. The Project´s steering group was manned by Landsvirkjun´s Deputy CEO, as well as four of the company´s Executive Vice Presidents, to make visible the importance of successful results in accordance with Landsvirkjun´s corporate strategy. Panel of experts was established to ensure that previously earned experience and knowledge was reflected over to the Project Team. The company support divisions submitted expertise regarding company strategic procedures such as legal, procurement, environmental aspects and research and development

The two levels of the Project Team, i.e. offsite- and on-site platform created the possibility of simultaneously operating the managerial part (off-site) taking on the project´s upper level and commercial function and the construction part (on-site) achieving a broad and well-functioning team with partly shared responsibility and roles.

The Project Director´s authority was defined as the project scope management regarding cost, schedule and result, including risk assessment, tendering and contracting but on-site management, synchronization of contracts and progress management according to schedule was shared to the resident engineer and the contract managers, all experienced employees of Landsvirkjun with long history of construction and operation of power plants.

The project clients were the company Energy Division as operator of all Landsvirkjun´s power plants, Landsnet – the operator of the Icelandic power grid and PCC Bakki Silicon.

4.1.2 Organizational structure

The project was led by a Project Director accountable for the project delivery and a core team of the Landsvirkjun experts who managed individual contracts. The core team included also the legally required Resident Engineer, Health, Safety and Environment management, project controls and site support personnel. Additional support was supplied from corporate home office for finance, procurement, legal services, communication, information technology and corporate safety support. Electrical and mechanical supervision support was supplied by personnel from the Landvirkjun Energy division as well as technical supervision on site for certain matter by consultant engineers. Geotechnical support for drilling of production wells was supplied by ÍSOR - Iceland GeoSurvey. Each individual contractor had its own organization with a project/site manager(s) responsible for their activities and for cooperation of all on–site construction activities. The organizational chart for the Theistareykir geothermal power plant project is shown in Figure 4.

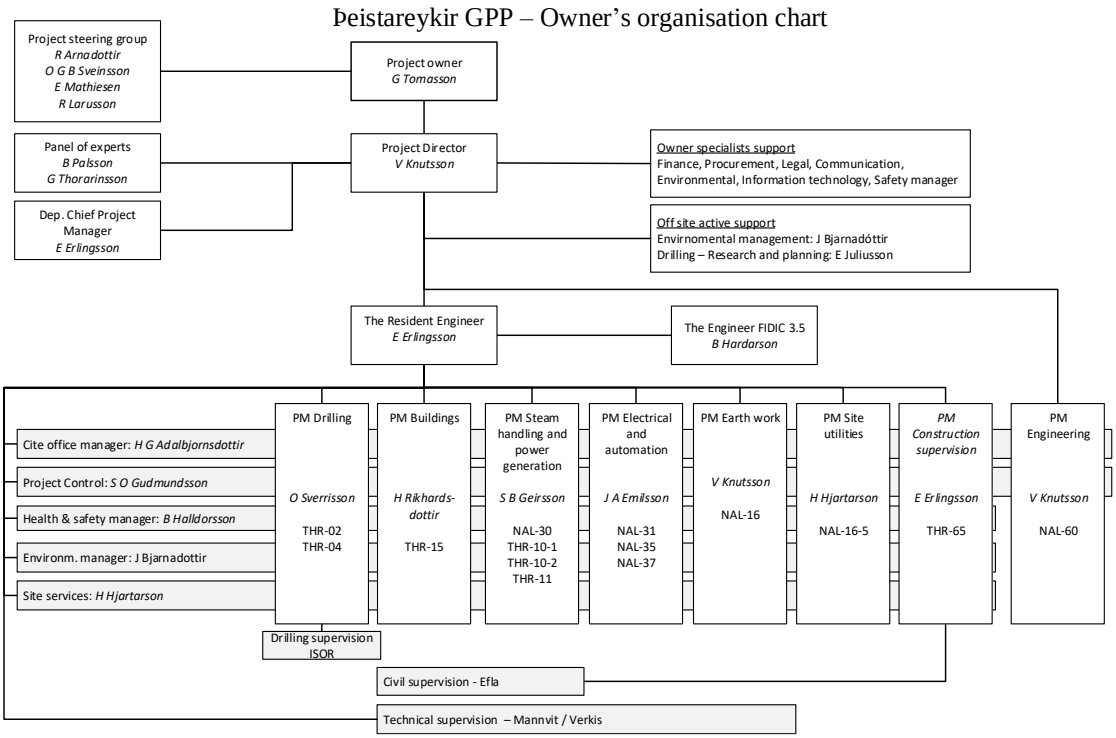

Figure 4: Owners project organization chart

To form a well functioning and coherent Project Team group an organization structure, see figure 4, and a RACI matrix, see Table 2, were defined, displaying the and roles and responsibility of the PT was defined. With a clear organization chart and a detailed RACI matrix the roles of individual positions/persons are defined and implemented into the work, both off-site and on-site.

Table 2: RACI (Responsibility, Accountability, Consult, Inform) matrix was used for identification of project member's roles and responsibilities

RACI R: Responsible A: Accountable C: Consult I: Inform Task \ role	Division manager / Project owner	Steering group	Chief Project Manager	Resident Engineer	Project Manager/ Contract manager	Cost controller	Scheduler	HSE manager	RISK manager	On-site services	Office manager	Divisional Quality officer	Byggingarstjóri	Design contractor	Construction supervision	Procurement divisiton	Procurement divisiton	Leagal team	Commonication specialits	LV Operations (Orkusvið)	Environmental division	Specialist group	LV safety manager	LV Environmental manager	Social Responsibility	The Engineer	DRB
Project initiation																											
Appointment of Project steering group and Chief Project Manager	A	I	I																								
Definition of Program Scope, Org. chart preparation and key contact personnel identified	A	C	R																								
Project Management																											
Stakeholder identification/evaluation and communication plan	C	I	A	R	R			R											I								
Planning and permissions	C	I	A	R	R			C					R	I	I			C		C	C						
Responsibilities of "byggingarstjóri"			C	R	C								A	R	R												
Contractors coordination and dispute resolution			C	A	R	C	R	C	C						C												
Resolution of claims and disputes	C	I	C	A	R	C	C							C	C			C								R	
Dispute resolution (Claim skv. FIDIC 3.5)	I		I	I	I																					A	
Dispute resolution (Dispute skv. *FIDIC 20.4*)	I		I	I	I																					I	A
Employers on site services			C	A	R			R		R	R									C							
Management of on-site project personnel			C	A	R	C	C	C			C																
Teambuilding and feedback to project personnel (and others)	I		A	R	R	R	R	R	R	R	R																
Supervision of project operation in line with company vision and values, laws and regulations and fulfilling the needs of operations	A	C	R	R																							
On-site visitors reception	I	I	C	A	R			R			R								I								
Communication with the media	C	I	R	R							I								A								
Project promotions	I		A	R							I								R								
Social responsibilities	A																										
Supervision of terms of employment (Chain responsibility)	A	I	R	R	R			R										R	C								
Contract management																											
Contracts scope and scope bounaries	C		A	R	R									C								C					
Contract negotiations	C		A	R	R	R	R	R	R					C			C	C				C					
Tendering	C		R	R	R												A	C									

Important guidelines to this work included the utilization of the skills and qualifications of each person, shared authority and responsibility to empower each and everyone in the team, as well as strengthening commitment to the project. The individuals of the PT were selected from different divisions of the company, and from outside the company when needed, to create diversity and

broadmindedness and to utilize the enormous amount of expertise and experience inside the company. The company's vision was to utilize prior experience and expertise in each field, ensuring that this experience was put into operation, see Figure 5.

Figure 5: Core competences related to project success were incorporated from outside sources and other company departments

Landsvirkjun's approach to successful project management has been to appoint its own employees to key positions within the organization, see Figure 4, to utilize expertise from different divisions of the Company. This includes specialists in construction management, HR, procurement, communications, environmental matters and geology. A panel of experts from prior projects was also established to transfer knowledge to the Project Team of the new power plant and the planned joint operational team of Theistareykir and the existing one nearby Krafla Geothermal Power Plant. The power plant engineers from Krafla were actively engaged in installation supervision of all major systems during the site construction period. The Project Team also included first entry professionals and summer students with different views and cultures, which contributed to innovation and different approaches during the project's execution.

When hiring consultants for the designing phase, an open tender process with double envelope system was used. This separates the technical proposal (based on and intended to meet the statement of work) from the financing or cost proposal in the form of two separate processes. This ensured that the expertise and knowledge of the consultant was evaluated important as well as the bid price in the selection of the successful consultant. In addition to this, external experience both from specialists in the field, as well as from domestic and international energy companies, was utilized as the project is complex in terms of geology and reservoir management.

Project Team members were given clear roles and responsibilities and they were encouraged to show initiative and take responsibility for the task they were assigned to, called upon for expertise and knowledge when required, and asked to back up other Project Team members as required. This created a united Project Team that established a long-term relationship, were opinions and views were shared and knowledge and experience gained for the benefit of all participants. As one might expect in a project this extensive, both in time and human capital, continuous monitoring and adjustments had to be made regarding staffing and its roles and responsibilities during the project´s life cycle.

Project Team members received the required training with a special emphasis on Health Safety and Environment, HSE, matters requiring all members to participate in comprehensive HSE training and new employees received training according to Human Resource department procedures. Project Team members were also encouraged to obtain necessary additional individual training as required and an example of such training were project management seminars based on the IPMA Project Manager Certification Program that were held during the project preparation phases and resulted in several certified Project Managers working on the project, Sedlmayer, M. et al (2015).

Contractors were aligned to the same vision as the Project Team and common objectives for results for the project were established at the initiation of the construction phase, in many cases building foundations for long-term relationships and an excellent project outcome.

4.1.3 Stakeholder engagement

Stakeholder engagement and consultations were an important issue from the beginning and a series of meetings were scheduled with landowners and other key-stakeholders.

Extensive stakeholder mapping was conducted for the project in its preparation phase and a communication plan was developed prior to the start-up of the execution phase. Figure 6 shows example of stakeholder classifications. The main objective was to be in continuous consultation with stakeholders, to improve the project, hear new ideas and angles to align the project results to the parties. Cooperation with the Occupational Safety and Public Health authorities, local fire brigades and labor unions on a special project advisory safety committee is an example of stakeholder incorporation according to Landsvirkjun´s policy and is beyond official and legal requirements. This showed great leadership, setting a great example for the attitudes of the rest of the Project Team. For more details on the stakeholder engagement, see Bjarnadóttir J. et al (2020).

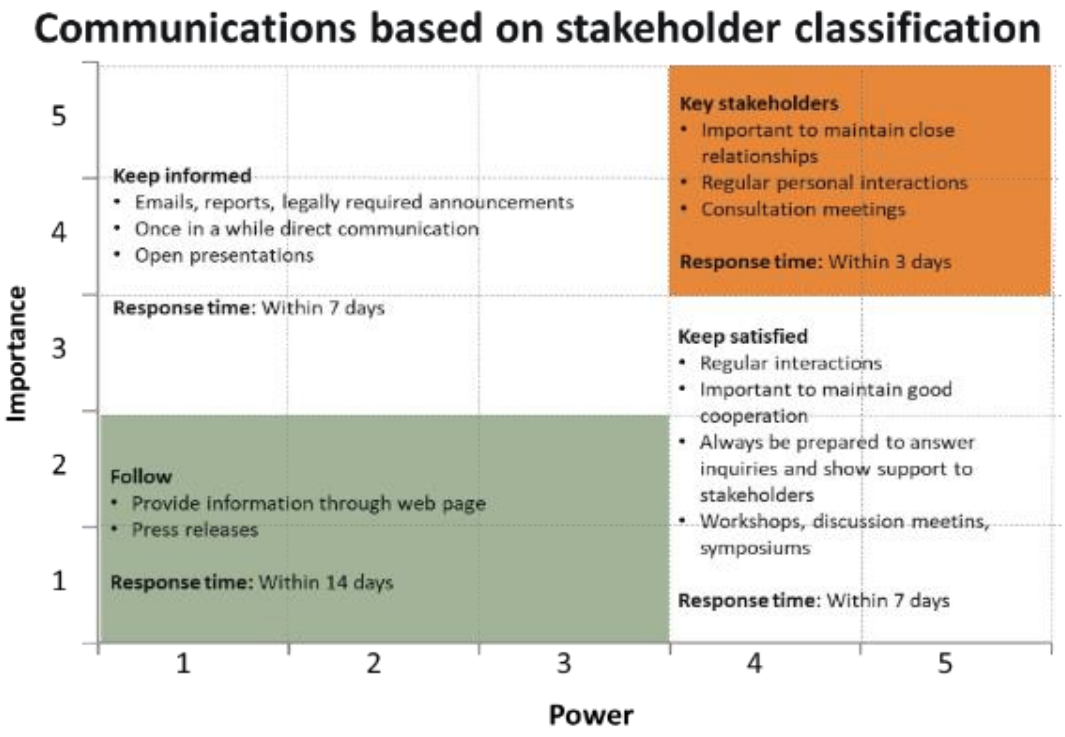

Figure 6: Stakeholder classification (Ref. 9)

4.2 Processes and resources

Several key processes and resources were developed for the Theistareykir Geothermal Power Plant Project to reach its objectives in an effective and efficient manner leading to successful project results. The processes and resources are divided into two categories; core processes and resources which are necessary to have in place and supporting processes and related resources that strengthens the core.

4.2.1 Project Management Processes & Resources

Project management processes were primarily organized through regularly reviewed and updated procedures and systems for the various topics. Figure 7 represents several processes and resources that were defined for the project, some of which will be discussed below.

Figure 7: Project management processes and systems – general overview

4.2.2 Information and document management system

The importance of a systematic and powerful information and document management system was recognized as being a fundamental precondition for successful project delivery. Based on experience from previous hydropower projects, the Project Team defined and set up a SharePoint based data management system for the exchange of design data between the designer, the Project Team and the contractors and as a shared workspace for handling of document and other project information.

All formal communication was conducted via the project web in a traceable way. The system reduced the need for the formal exchange of information through emails and ensured that the same information was available to Project Team members, consultants, contractors, civil- and technical supervisors and other relevant stakeholders based on their access rights which were easily managed on an individual or group basis. The review and formal submittal of drawings and other design documents was managed through the system which automatically notified the relevant individuals of the receipt of documents or changes in status of individual documents. The system was continuously adapted based on regular reviews of its functionality and of the project's needs. Figure 8 shows an example for process for contractor drawings within the SharePoint document management system.

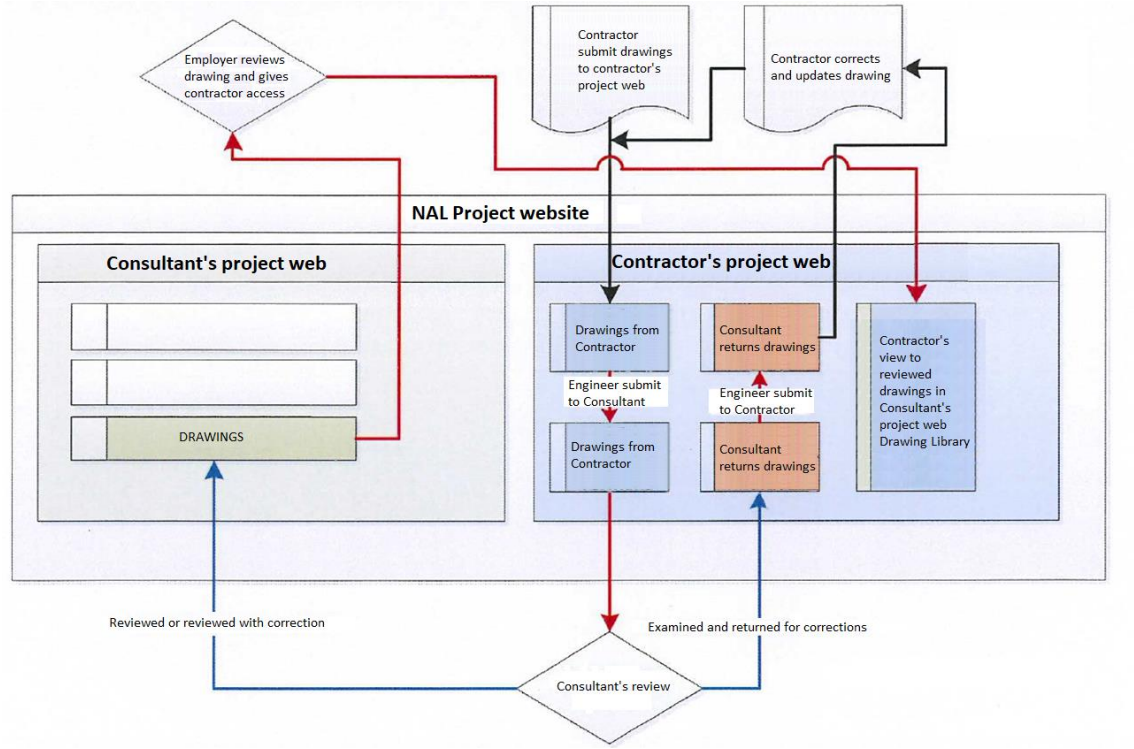

Figure 8: Process for contractor drawings through project web

4.2.3 HSE management system

The system includes a special SharePoint site for Health Safety and Environmental related topics, HSE. Project Team members were able to report HSE incidents such as dangerous working conditions to simplify the notification process giving the HSE manager a valuable tool to manage daily activities to ensure safe working conditions for all workers at the construction site.

An HSE training program was introduced with general training for all personnel working at the construction site and specialized training for specific activities. The training program was under continuous review and new topics were added as the project progressed and new challenges appeared. A system for work permits, based on risk assessment was introduced and root-cause analysis was performed on accidents. The outcome was used to improve work preparation and working conditions with the aim of making the project safer for everybody. Systematic risk control methods were developed and regularly reviewed and improved. The project went beyond governmental requirements when a special advisory safety committee was established involving contractors, local fire and emergency services and local labor unions. The project also made special arrangements with local health authorities regarding the health care of its employees and contractors.

4.2.4 Procurement and contract management

Landsvirkjun is a government owned Limited Liability Company and therefore adheres to the strict procurement regulations of the European common market. Tendering and contracting is therefore done under strict procurement procedures where due process and impartiality are key aspects to ensure fair treatment of all potential participants in the projects tendering process. Contract conditions were partially based on the Icelandic standard IST 30, Conditions of Contract for Building and Works of Civil Engineering Construction, R. Gunnarsson et al. (2012) and on FIDIC Conditions of Contract for PLANT and Design Build (The Yellow Book), see FIDIC® (1999). The selected conditions were the basis for the management of each contract and a clear process for disputes was also established.

4.2.5 Budgeting and cost control

Landsvirkjun has a long history of well-established methods for cost estimation and budgets for large construction projects as an industrial leader in large construction projects in Iceland since its establishment in 1965. The company financed, established and maintained a cost database commonly used by local engineering firms when establishing cost estimates for the company and others. Cost estimates are based on approved methods where the level of engineering detail is used for increased accuracy.

The company applies stage gate process as outlined in Figure 9 for project preparations and final decisions on commencing the construction phase are made by the company board based on the available cost estimates, schedule, scope definitions, risk assessments, business case evaluations and other important factors. The accepted cost estimate and schedule become the control budget and schedule.

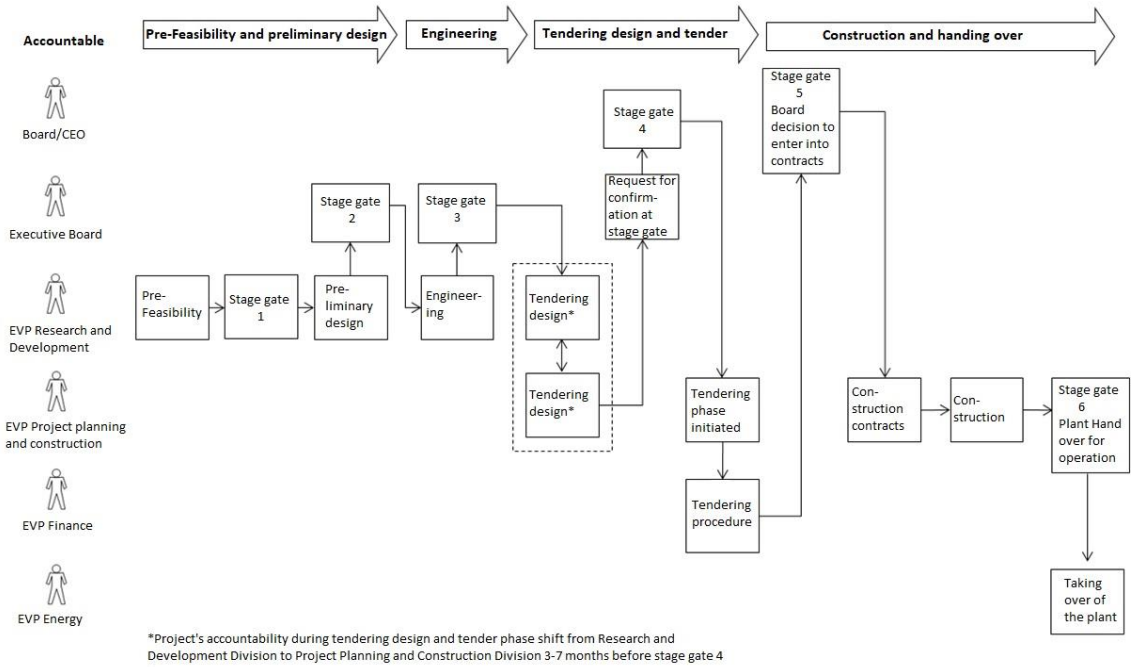

Figure 9: Landsvirkjun principal process for development and construction of powerplants

The project cost control approach varies according to the nature of individual contracts. Civil construction contracts are typically quantity based while contracts for turbines, generators and other specialized power plant systems and components are typically design, supply and installation contracts. While the company generally applies earned value cost control methods for quantity-based contracts, it applies simpler progress estimation methods for other contract types. Cost control is based on progress and contractors invoicing on a monthly basis with regular forecasts of final costs and cashflow in all cases. The Estimated Cost at Completion of the project was therefore visible at all times.

Scheduling during the construction period is based on progress reporting by individual contractors and the company maintenance of an overall schedule that includes major milestones. The individual contractor's schedules are a fixed topic in regular progress meetings and additional coordination meetings between contractors are managed by the resident engineer with support from the project scheduler. During critical periods, schedule meeting where sometimes held with contractors on a daily basis to ensure seamless cooperation and the progress of critical tasks.

4.2.5 Sustainability

Landsvirkjun has established an ambitious strategy on corporate social responsibility, CSR, see Figure 10, which states that it is the company's role to create value, to respect and protect natural resources and the environment and to share its expertise to effectively contribute to society.

Figure 10: Landsvirkjun has established an ambitious strategy on corporate social responsibility

In 2015, a voluntary initiative launched a regional sustainability project for North-East Iceland to fulfil the objectives and strategy of the company's CSR policy, in cooperation with local municipalities and the University of Akureyri Research Center. The Húsavík Academic Center was hired to manage the project, where among others, key project stakeholders, Landsnet, PCC Bakki Silicon and various tourism associations participated. The objective of the program was to develop KPI's with the local community to scientifically assess changes to society, the economy and the environment within the region affected by the construction of the ÞGPP. The KPI's were developed during the preparation and early construction phase of the project and can be seen in Figure 11. The initial results were made available to the public in 2018 via the project web-site www.gaumur.is, see Gaumur (2019).

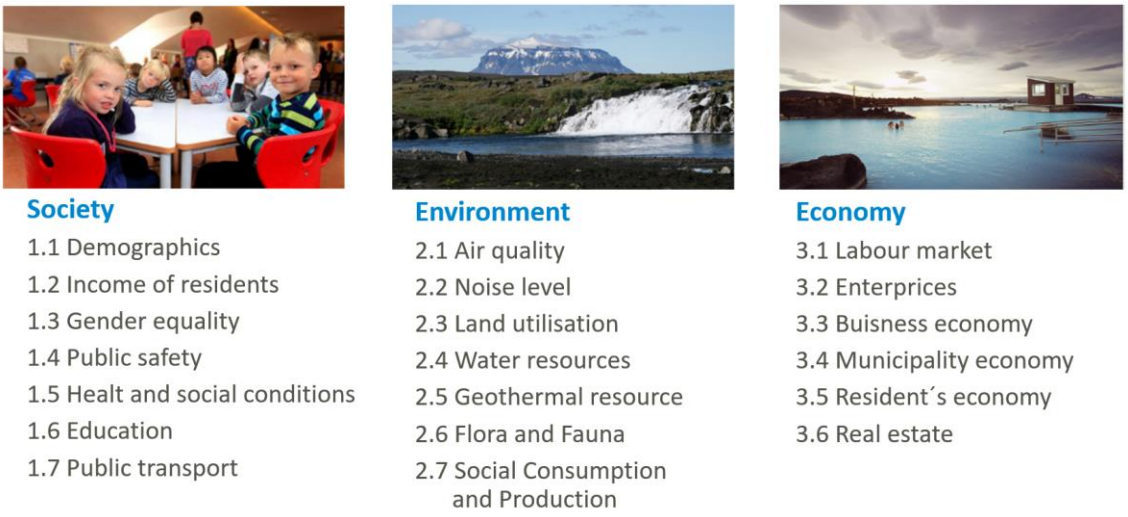

Figure 11: KPI's for the North-East Iceland Regional Sustainability Project (Ref. 18)

4.2.6 Environmental management (EM)

Landsvirkjun has an effective governance framework regarding environmental matters, as seen in Figure 12, which laid the foundation for the EM in the project. Significant environmental aspects and mitigation and monitoring opportunities were identified and implemented early on in the preparation stage, via strategic environmental assessments, land use plans and the project's Environmental Impact Assessment. A very high importance was placed on close cooperation with stakeholders in the local community, expert agencies and licensors. The results were recorded in the project's Environmental Management Plan along with the company's requirements. The Theistareykir area has a conservation value regarding landscape, geological formations, recent lava formations, geothermal flora, cultural remains and it is partly classified as a Natural Conservation Area. These issues were given special consideration during the development of the site plan to prevent any disruption of protected areas.

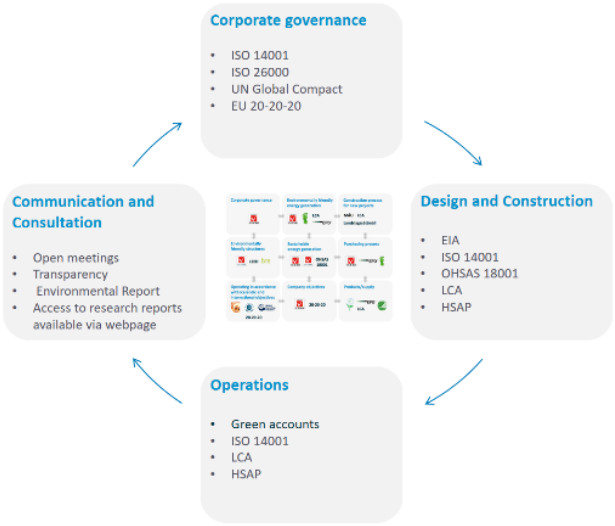

Figure 12: KPI's for the North-East Iceland Regional Sustainability Project (Ref. 18)

Regular monitoring has been conducted on environmental aspects since 2012 as a part of the EMP. Figure 13 shows some of the parameters that have been monitored. The objective of regular monitoring is to recognize the baseline for environmental conditions before operations begin and to subsequently monitor these parameters after the power plants start-up. The results are accessible on the project website , see Þeistareykir (2019) as well as several presentation videos on environmental monitoring within geothermal areas on Landsvirkjun's web page. The results can also be accessed through the Company's Green Accounts, for the year 2018 see H. Sigurjónsson et al (2019).

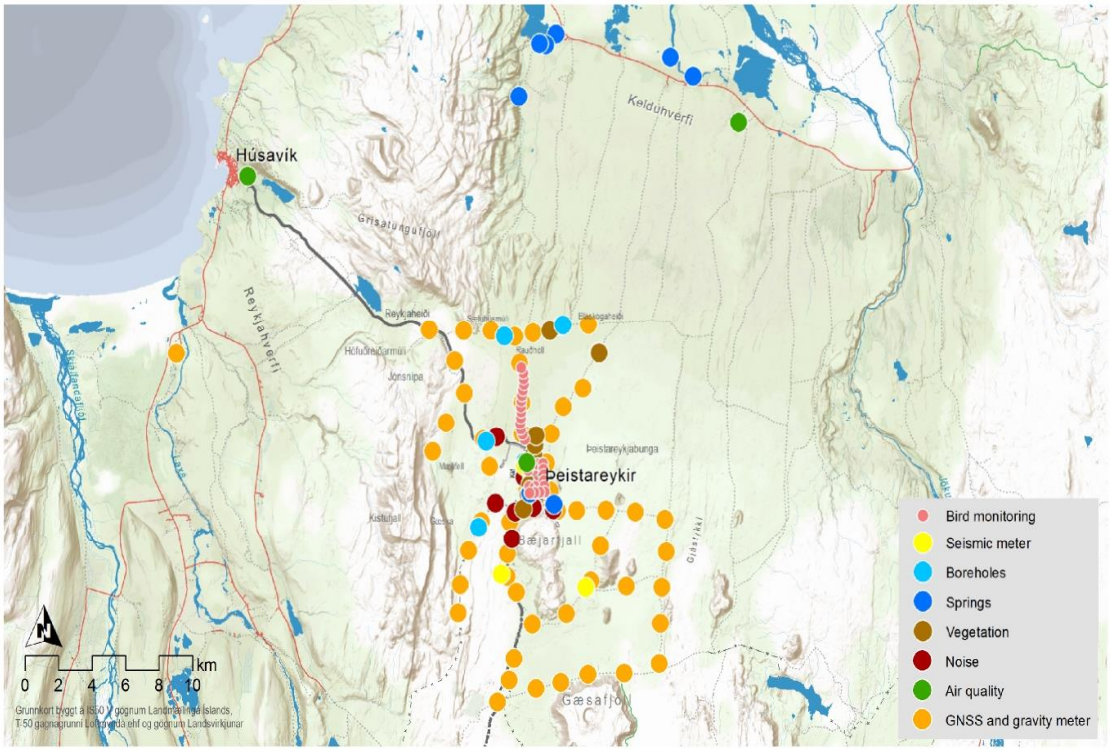

Figure 13: Environmental monitoring for the Theistareykir Geothermal Power Plant Project

Land reclamation plans were put in place to address land use concerns brought up by land owners to replace land disrupted by construction. The plan was implemented in 2014 and followed during construction. A total of approx. 160 hectares of land has been re-vegetated and an emphasis was also placed on completing finishing work alongside construction. This included the closure of quarries as the project progressed and only active quarries remain open. Figure 14 shows the functionality of the EM within the Theistareykir Geothermal Power Plant Project.

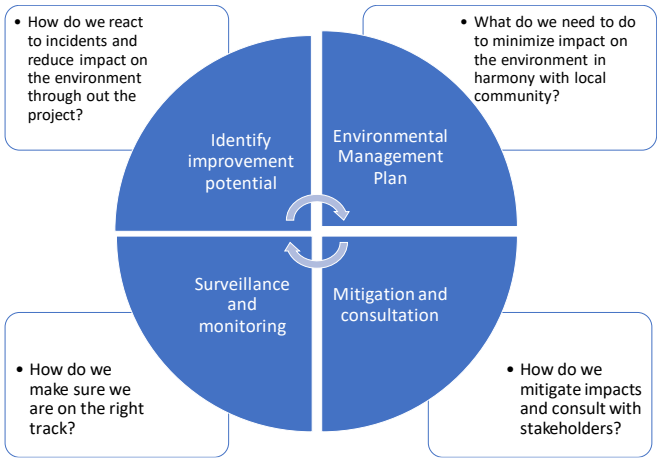

Figure 14: The continuous cycle of the EM for the Theistareykir Geothermal Power Plant Project

4.2.7 Communication and Consultation

A special emphasis was placed on communication and consultation A comprehensive stakeholder management plan and communication process was in place and actively monitored. A communication plan for each calendar year was developed and the time, frequency and method of communication with each defined stakeholder was decided at the end of the previous year. A part of the stakeholder management was to register all stakeholder communication and plan for further communications with each stakeholder. A contingency plan was in place if needed, as seen in Figure 15.

Figure 15: Communication contingency plan

5. PROJECT RESULTS

The project results are the real indicators for evaluation on the project´s execution and how successful the harnessing of the geothermal resource at Theistareykir has been so far. Project results consist of many different things such as the actual project deliverables, i.e. project cost, project startup, technical function and plant´s reliability and those can be measured by conventional methods by evaluating how well the project´s objectives has been met. Other items such as customer satisfaction, project team satisfaction and stakeholder satisfaction are equally important to measure as part of the overall evaluation of the feasibility of harnessing geothermal energy as one part of the global energy transformation from fossils to renewable resources.

5.1 Customer Satisfaction

The main objective towards the customer, i.e. the Energy division of Landsvirkjun and Landsnet, the operator of the Icelandic Power grid, was to build and deliver a reliable geothermal power plant to increase availability and reliability of electrical energy in North-East Iceland and create opportunities for better social and economic circumstances by use of electric energy in the plant´s affected area.

After commissioning of the plant, the feedback from the Production Planning Dep. of Landsvirkjun´s Energy division, shows that the reliability of the Theistareykir Geothermal plant is rated as "outstanding" compared to other greenfield projects of Landsvirkjun. Registration of unplanned outages displays result fully comparable or better than most of the other geothermal power plants in Iceland.

Collaboration with Landsnet, the operator of the Icelandic power grid, is highly rated and has been presented both in paper at the Geothermal Research Council (Hardarson et. al (2018)) and at the Iceland Geothermal Conference (Heimisson et al (2020)). Along with comments like "…improved damping of power oscillation both in the overall system and in the local system in case of islanding, improving the overall system stability", leading to Landsvirkjun´s and Landsnet´s collaborating further work on a smart-grid scheme for the Theistareykir power plant. Landsnet also commented that "… the project´s success in innovation, delivery and dissemination shows the excellent level of collaboration between Landsnet and Landsvirkjun on projects of national significance."

Feedback from the energy intensive end user, PCC Bakki Silicon, as Landsvirkjun´s energy consumer has been positive and organized collaboration with the company as well as Landsnet took place on a weekly base during commissioning of the power plant that extended through almost one year of commissioning of PCC Bakki. During that period, Landsvirkjun adjusted the power plant commissioning towards PCC's need and assisted in every possible way. During the ÞGPP construction phase, represents from PCC and their investors visited the project site several times to visualize the physical progress and to gain confidence regarding timely and reliable delivery of the electrical power and efficient project management of Theistareykir Geothermal Power Plant Project during construction.

5.2 Project Team Satisfaction

Landsvirkjun´s strategy is to operate a family friendly working environment, including on-site workplaces of construction projects. The Project Team decided to define the on-site continuous working period as max. 5 working days, Monday to Friday, unless emergent circumstances required otherwise. Accommodation was a personal double room flat or a personal room with bathroom and shower. Access to high-speed internet connections served the purpose of modern communication to family members when located on-site as well as individual TV connections for each apartment. The high-speed connections also made it possible for remotely join on-site meetings, discussions and planning for individuals unable to stay on-site. By this the consistency in collaboration in the Project Team was preserved. All travelling longer than 1,5 hours used airline connections to minimize the travelling time.

Definition of Project Team roles and responsibilities (see RACI in Table 2) strengthened trust and confidence inside the Project Team and individuals took on an active part in the project management creating a platform for teambuilding and teamwork. Clear roles and responsibility brought up respect and recognition of individual positions of the Project Team as well as contractors and consultants.

An important objective of the Project Team was to generate a common interest and vision on the projects results among all the project´s participants. This applied to Landsvirkjun´s employees, consultants, third party supervisors and contractors. Working toward such objectives with the common vision to achieve new benchmark project results for the geothermal sector made everyone´s contribution a valuable part of the project and required an excellent collaboration among team members. During the project execution, experience and good performance resulted in personal carrier progress within the Project Team and the company.

The Theistareykir area created opportunities for the Project Team members to enjoy both winter and summer outdoor activities in the beautiful environment. The company encouraged such activities by establishing facilities and equipment for training, winter and summer traveling in the mountainous area and by organizing special trips for sightseeing and exploring the region. Major milestone celebration with all project participants were also highly appreciated.

The good team spirit was preserved through the project and now when project closing is approaching, the strong relations inside the Project Team has raised the level of the company's collaboration between divisions, towards the consultants and to the contractors as a foundation for a long-term collaboration.

5.3 Stakeholder Satisfaction

The main objective towards other stakeholders, i.e. among others the public, municipalities, land owners and contractors, was to communicate in an effective way the planned activities, the project progress and plan and execute countermeasures as part of mitigation of the projects impact. Participation in a yearly open survey to the public with questions regarding the project, it´s

positive and negative impact on the community and hearing the public´s concerns, expectation and suggestions for improvement displayed a positive attitude and hope for beneficial result.

An early start of environmental monitoring and starting of land reclamation and preservation of surface vegetation at the project´s preparation stage proved to be very important and was viewed as a positive act of Landsvirkjun. The planned monitoring and disclosure of all results was a base for trust and a fruitful collaboration between parties.

Start-up of the North-East Sustainability Project turned out to be an important way of monitoring the project´s social-, economical- and environmental affects in a scientific way by external third party agencies like universities and official recognized agencies. A separate collaboration with companies and stakeholders inside the regional tourism turned also out to be stimulating for the local industry. The project included a construction of an access road at the construction site which opened a public access to an area that had previously been out of reach for the public. Now, with the new standardized public road to the Theistareykir area, a regional planning work for utilization of the area for outdoor sport activities and organized tourism has started and is planned to become active within a few years to come.

The GSAP assessment created an excellent opportunity to get feedback from the broad range of internal and external stakeholders and an evaluation on how the project´s preparation and construction had turned out. The positive results displayed in Figure 16 indicate best practice performance, or an establishment of new best practice, see Hartmann J (2017).

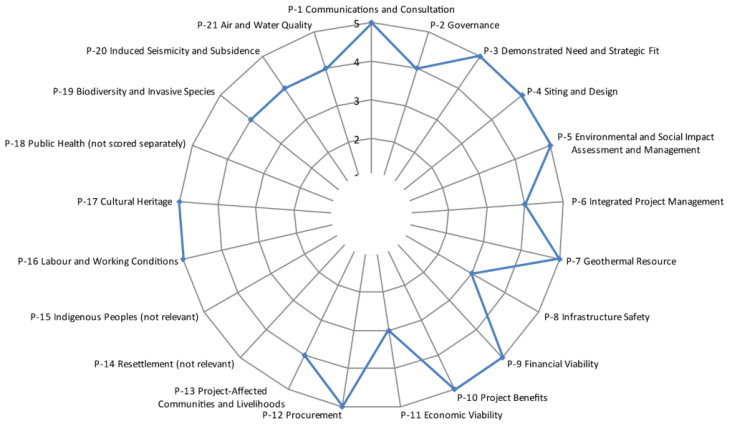

Figure 16: Results of GSAP assessment

References from key stakeholders such as Municipalities, the Soil Conservation Service of Iceland and contractors participating in the project witness the positive communication and collaboration that took place during the project. This has also created a foundation for further collaboration between parties for upcoming projects.

5.4 Project Results and Impact on the Environment

Evaluation of the geothermal energy source during the execution phase and after the startup of the Theistareykir Geothermal Power Plant Project has shown that the main objective of sustainable utilization of the geothermal resource has been successful. Following up on two reservoir capacity tests, during the project preparation phase, where all steam wells stayed fully open for duration of 6 to 8 months without indication of any capacity reduction the reservoir is monitored by capacity measurements of each well. After two years of full load operation no measurable declining of wells has been detected. Parallel to this participation in an international research project on monitoring of mass and stress changes in the geothermal reservoir, Landsvirkjun is making huge effort in monitoring the reservoir.

The construction of the 90 MW_e geothermal power plant was according to schedule and power was supplied into the power grid as planned. A part of the project was to drill up to 8 steam wells to meet the plant steam demand. Available steam is sufficient for 110 MW_e, so there is an existing surplus capacity of 20 MW_e. The project construction cost is now, close to project closing, according to budget (0,4% below budget).

Systematic and structured management of testing and commissioning using a coherent database for planning and executing all works resulted in outstanding performance of the plant during the first two years of operation.

Collaboration with landowners as key stakeholders from the early preparation stage throughout the project is reflected in reference letters acknowledging good result regarding land reclamation, information sharing and reaction to comments and requests. Official closure of all environmental countermeasures has been acknowledged by the involved stakeholder and confirms that all objectives have been achieved.

Monitoring of the project’s environmental impact has been according to the Environmental Monitoring Plan where results of yearly inspection is publicly disclosed at Landsvirkjun´s webpage. No serious environmental incidents occurred during the project.

5.5 Results Beyond Project Objectives

After approximately two years of full load, 90 MW_e, operation, the reliability of the plant and the plant´s functionality regarding improved electrical grid stability on voltage and frequency has been proved. Further development of the recently developed smart grid functions with the plant as an active partner of Landsnet´s grid operation is a testimony of the plant´s enhanced function. The plant´s geographical location and it´s connection to the weak power grid in the North-East Iceland has created new alternatives for industrial opportunities in the area because of both increased power availability and electrical stability. The smart grid functions described above defined a new benchmark for operation of geothermal power plants in Iceland.

The result from the GSAP assessment highlight Landsvirkjun´s sustainable approach to the project and how the PT exceeded the official requirements and the initial project objectives. Operation of the North-East Sustainable Project in collaboration with stakeholders and research institutes shows further a strategic act for gaining independent information of the project´s public affects.

6. CONCLUSION

The Theistareykir Geothermal Power project has been ongoing since 1999 when preparation work and research on the geothermal field began by an association founded by local municipalities and regional utility companies. From the beginning one of the main criteria were to prepare and construct a geothermal power plant utilizing natural resources in a sustainable way. Value creating and feasibility of the project are guiding principles. At the same time safety and environmental matters have been at the forefront during the project execution. Now, at the end of project execution time the predefined objectives of the plant´s function and power capacity has been met, the construction cost is according to budget and the planned time frame has been kept.

The foreseen changes of the global energy market toward utilization of renewable energy resources clearly put geothermal energy resources among the most attractive ones. The way how geothermal resources are harnessed, i.e. the research's work, the project design and project management, project results and the impacts that construction and operation of geothermal power projects has on the three pillars of sustainability, i.e. environment, economy and social affects will turn out to be the highlights evaluated when the feasibility of geothermal projects as one of the options to meet the future need of energy transformation from fossils to renewable ones. The Theistareykir Geothermal Power Project participated in the 2019 IPMA Global Project Excellence Award for large and mega sized projects worldwide, where the project is evaluated and compared to a number of other projects. The IPMA PE – award committee has now announced the Theistareykir Geothermal Power Plant Project is one of the two finalists for the award in the large size group and the results will be made public at the 31st. IPMA World Congress in Merida, Mexico, in October 2019. This award appointment will without a doubt show that harnessing of geothermal power can be executed according to best practice of project management with result that are benchmarking for the geothermal power industry.

It is Landsvirkjun's hope that the knowledge from the Northern Sustainability Project will proof, through the years to come, that the company has reach its objectives which are to prepare and construct a 90 MW_e Geothermal Power Station utilizing natural resources in a sustainable way and the outcome, the Theistareykir Geothermal Power Plant will be a testament to the positive impact of Landsvirkjun in Iceland.

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