# Geothermal Wastewater Management to Create a Circular Economy: Taking Advantage of the Abundant Thermal Wastewater in Iceland

Nature-based Solutions for Circular Management of Urban Water

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# Chapter 12
# Geothermal Wastewater Management to Create a Circular Economy: Taking Advantage of the Abundant Thermal Wastewater in Iceland

**Samaneh Sadat Nickayin**

**Abstract** Iceland is a geologically active land and home to some of the world's most active volcanoes and the largest glaciers in Europe. In this northern sea island, water is the most influential element in the economy and planning strategy of islanders' everyday life. Water comes in all forms, both as a provider and a threat. Water is a crucial element for Icelandic industry development, which is one of the pioneers in hydropower and geothermal energy production. This commentary is a synthesis of different Icelandic case studies to manage geothermal wastewater in a circular economy to reduce the environmental impact of such wastewater.

**Keywords** Geothermal energy · Iceland · Placemaking · Circular economy · Wastewater

## 12.1 Introduction

As fishing is the economy's primary source in Iceland, most urban settlements were built around the rich fishing resources along the coastline. Dwelling with water is the origin of Icelandic urbanity, which relies on naval resources and waterworks.

The urbanisation development initiated a new chapter of energy production in Iceland, which was mainly focused on abundant water. During the past century, Icelanders imported coal, kerosene and the traditional national peat for heating and cooking. The burgeoning of urbanisation has led to the construction of new energy implants, using natural and abundant geothermal heat and hydropower sources for heating and electricity generation.

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The first Icelandic hydropower station started operating in Hafnarfjörður, near the capital area, in 1904. Reykjavík in 1921 and Akureyri in northern Iceland got electricity from hydropower stations in the early 1920s.

For centuries, Icelanders used natural geothermal springs for bathing and washing, but in the first years of the twentieth century, hot water began to be harnessed for individual heating homes, which today is considered the most successful story of the geothermal community.

Due to the abundance of hydropower and Geothermal energy production, local authorities focused on the central engine of industry in energy production, providing incentives for different multinational companies with high electricity demands to be based in Iceland. For instance, metal manufactories are the most crucial power-intensive industry in Iceland, consuming almost 50% of total electricity production; fishing and agriculture are the other two prominent sectors of energy consumption in Iceland (IEA, 2012).

This chapter focuses on geothermal energy extractions and how wastewater reuse created a circular economic model within the industry and domestic use.

The extraction of geothermal energy requires hot water reservoirs. The central geothermal energy plants in Iceland are located in hot areas of Hveragerði, Grindavík, Þingvellir, Reykjahlíð and Húsavík with a total capacity of 802.5 MW (Mikhaylov, 2020). By drilling a well through the ground, the geothermal fluid, consisting of a combination of water, vapour and minerals, is extracted and fed to the geothermal power plant to power a turbine to generate low-cost electricity. The temperature of the extracted fluid could vary between 400 and 60 °C. The power-plant wastewater can be injected back into the well or discharged into nature. The former solution is costly but can be feasible for large and long-life wells. The latter is harmful to the environment as it contains salt and minerals. To mitigate such a damage, it is possible to treat the water via a three-phase distillation process to separate the salts and minerals from the water to obtain clean water.

Most studies focused on desalination and chemical stress assessment of geothermal wastewater. However, in past years, different innovative approaches found the potential of reusing geothermal wastewater to create a new circular economy model. The following circular strategies aim for holistic societal resiliency in the face of global climate change. The circular solutions proposed emphasise food security, leisure activities and waste management to minimise the detrimental impacts of geothermal wastewater and provide a venue for innovation and collaboration for a resilient community.

## 12.2 The Industrial Site and Leisure Activities

### *12.2.1 Blue Lagoon and Nauthólsvík Geothermal Beach*

Geothermal is not only a source of energy production but also a heat source in swimming pools, creating the beating heart of urban social life in all Icelandic towns. Being an island, swimming has been considered a survival skill in Icelandic culture, and during the 19th Iceland became one of the first countries to pass Legislation enabling municipalities to introduce swimming as an obligatory part of its school curriculum; each student should at least complete 20 h of swimming every year (Lög 25, 1940; Lög 39, 1925). The reasons for such a choice are due to the security issues of islanders (as fishing is the core of society), Icelandic cultural heritage, and the promotion of public health (Bogadóttir, 2021). Such urban bathing culture attracts millions of visitors annually to enjoy Iceland's 'wellness industry and spa culture'. The design of swimming pools and hot tubs must guarantee the site's energy efficiency. The *Blue Lagoon* and *Sky Lagoon* are the two most prominent design prototypes for wellness industry spas.

The *Blue Lagoon* results from an accidental by-product of the Svartsengi geothermal plant power opening in 1976. As water cannot be recycled because of its high concentration of minerals, the surplus of wastewater from geothermal plants has been led into the lava field. The high silica concentration created soft white mud at the bottom of the lagoon. The *Blue Lagoon* has grown incredibly over the last 40 years, and in 2012, *National Geographic* published a list of Wonders of the World,[1] including the *Blue Lagoon* in the Water category and shared this recognition with the esteemed company. The title of "Wonders of the World" outlines the crucial role of "Calibrated and perceptive architectural, wellness, and hospitality design" (Bogadóttir, 2021) that demonstrates the potential of geothermal wastewater as a recreational open space that emancipates through global promotion, yielding twenty-two millions of profits even during COVID-19. Besides the swimming pool, the Blue Lagoon company produces a wide range of natural skincare cosmetic products using the ground sea, silica, minerals and algae. The Blue Lagoon is a demonstration of an astute circular economy that eliminates wastewater and pollution, circulating products and materials, and the regeneration of nature, which have been at the centre of the business model development (Fig. 12.1).

The artificial Nauthólsvík Geothermal Beach of downtown Reykjavik is another example of geothermal engineering technology with the idea of elevating the temperature of a small part of the North Atlantic Ocean with discharge wastewater from the Reykjavik district heating system so that the temperature of the lagoon can become as high as 18–20 °C in the summertime (Snaeland and Sigurbjornsdóttir, 2010). The combination of warm ocean water and the glistening golden Moroccan sand allows a bizarre sensation of being in the middle of the North Atlantic and Arctic oceans and indulging in some summertime frolicking. Thanks to the best Icelandic geothermal complexity engineering, the bay of Nauthólsvík has a Blue Flag certificate – an award conferred to environmentally sustainable beaches with high eco-friendly standards.

[1] The official word of National Geographic Wonders of the World 2012, to describe the wonder for the water of *Blue Lagoon* is: "Iceland straddles the Mid-Atlantic Ridge, where the North American and Eurasian tectonic plates are pulling apart. Upwelling magma built the island and heats its vast reservoirs of water, creating a geothermal paradise. First among the country's many simmering geothermal pools is the Blue Lagoon, a turquoise vision in a black basaltic moonscape. The geothermal spa is fed by seawater 6500 feet (1981 m) beneath the surface, where it reaches a searing 464 °F (240 °C). Capturing silica and other minerals on its way to the surface, it emerges from the ground at a balmy 100 °F (38 °C), just right for pampering visitors".

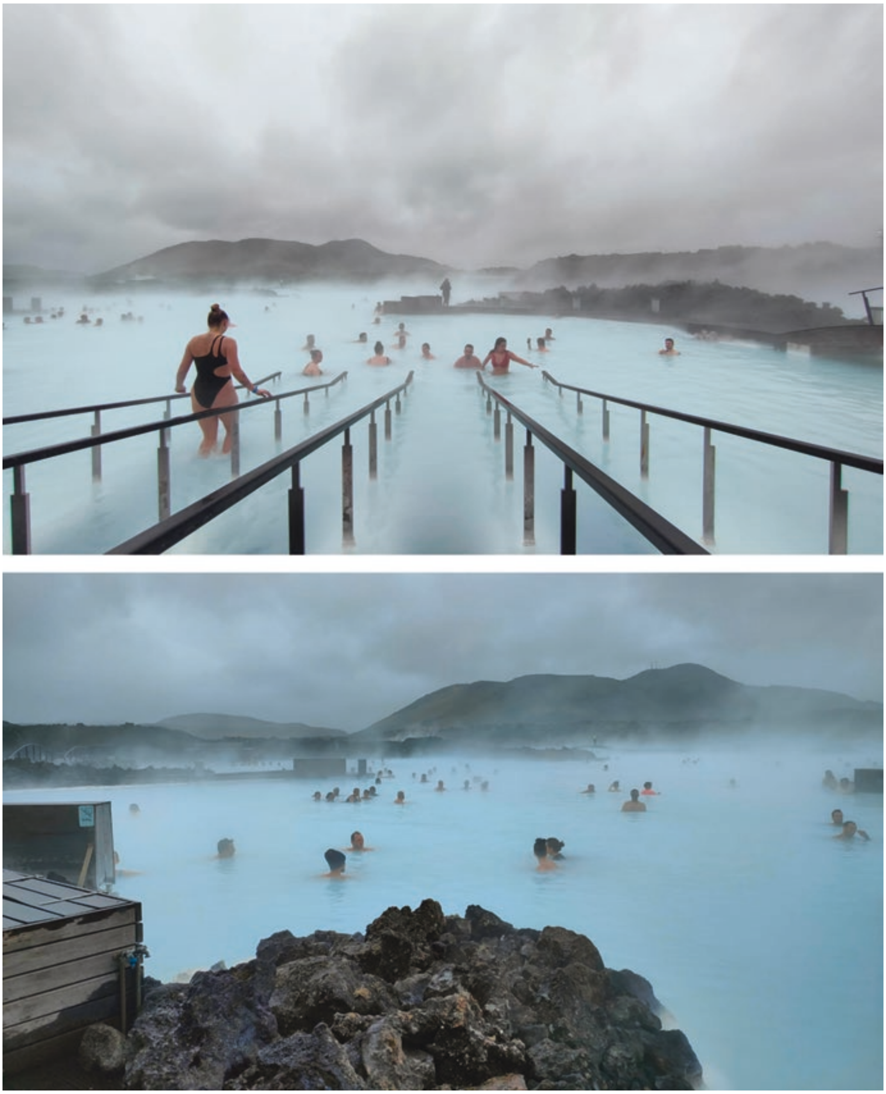

**Fig. 12.1** Blue Lagoon. © Francesca Perrone

The use of geothermal resources for bathing and swimming, recreation, relaxation, socialising, and therapeutic treatment has deep roots in different cultures around the world, a tradition that undoubtedly remained much the same through the centuries in all corners of the globe. However, modern technology has made it possible in a better condition, where "resource recovery" (Allenby, 2006) and "industry ecology" (Iacovidou et. al, 2017) are blended to create great potential in the "wellness and leisure industry" (Fig. 12.2).

**Fig. 12.2** Nauthólsvík Geothermal Beach. © David Christian Finger

## 12.3 Greenhouses and Outdoor Agriculture

### *12.3.1 Friðheimar and ALDIN Biodome*

The usage of geothermal wastewater is not limited to the outdoor public swimming pool and spa design; it is essential for local food security and production in Iceland. Iceland relies on other countries for half of its food supply and necessary inputs for food production. If food imports were discontinued, Iceland would be unable to feed its population. The history of Iceland's shift from self-sufficiency to import reliance reveals that the domestic agricultural sector weakened significantly, and the country's carbon footprint increased tremendously. Given Iceland's sparse arable land and harsh climate, greenhouses provide more variety, longer growing seasons, and a greater yield of crops that could be achieved in the traditional method (Garðarsdóttir et al., 2021). One of Iceland's oldest and most important usages of geothermal wastewater is heating greenhouses. The total geothermal energy used in Iceland's greenhouse sector is estimated to be 740 TJ annually (Ragnarsson, 2003). Modern greenhouse technology makes it possible to grow almost everything in Iceland, from lettuce and peppers to bananas, melon and grapevines, though some plants require more intense care or costly treatment and harvesting. The idea of a sustainable, authentic food experience, eating bananas grown in Iceland or enjoying a cup of Icelandic coffee directly from the tree in a greenhouse-café is sure to be competitive amongst a growing number of tourists and people

**Fig. 12.3** Greenhouse in Reykir with banana and coffee plantation. ©Samaneh Nickayin

willing to pay for the quality and the consciousness of where the food comes from (Garðarsdóttir et al., 2021; Helgadóttir, 2017) (Fig. 12.3).

Today, greenhouses are part of the "indoor" public space realm; for instance, Friðheimar Greenhouse is a restaurant where geothermal heating technology makes indoor horticulture possible. Friðheimar is a gratifying restaurant that demonstrates the art of "placemaking" where the hidden, hot water pipelines flourish the fragrant tomato plants, creating an inspiring example of "circular Agriculture" (Ministerie van Algemene Zaken, 2017)" where the users can enjoy the feast of tomato soup with freshly baked bread (Fig. 12.4).

Geothermal steam is commonly used to boil and disinfect the soil in greenhouses. However, geothermal wastewater has been used in several locations to thaw the soil, enabling the vegetables to grow and be brought to market during early spring. Soil heating is not a growing method because similar results could be obtained at a lower cost by covering the plants with plastic sheets. However, it is estimated that about 120,000 m$^2$ of fields are heated this way (Garðarsdóttir et al., 2021) and according to the research conducted in Iceland, the data appears to support the hypothesis that heating with low-grade wastewater can have a meaningful positive impact on plant growth rates.

*ALDIN Biodome* is a pilot project in Elliðaárdalur valley in Reykjavík to investigate the impacts of (and optimal configurations for) the use of thermal wastewater

**Fig. 12.4** Friðheimar Greenhouse. © Þórunn Edda Bjarnadóttir

in outdoor cultivation with insulated beds in an attempt to increase the outdoor crops. Hjördí Sigurðardóttir, the founder of *ALDIN Biodome*, highlights that almost 85% of all houses in Iceland are heated with geothermal energy; thus, low-grade warm water is particularly abundant per capita in Iceland, as the outflows are discharged at around 30 °C, the disposal of such water is harmful to the environment causing thermal pollution.

Despite favourable conditions like abundant summer sunlight, the cold Icelandic summers create difficulty for cultivation due to low soil temperatures. According to the research conducted by ALDIN Biodome, the data support the hypothesis that heating with low-grade wastewater can have a meaningful positive impact on plant growth rates (circa 20–180%, depending on the bed, lighting, and choice of metric) (Róbertsdóttir, 2020; Vsó Ráðgjöf Ehf, 2020). However, little benefit was realised in terms of extending the growing season of sensitive plants.

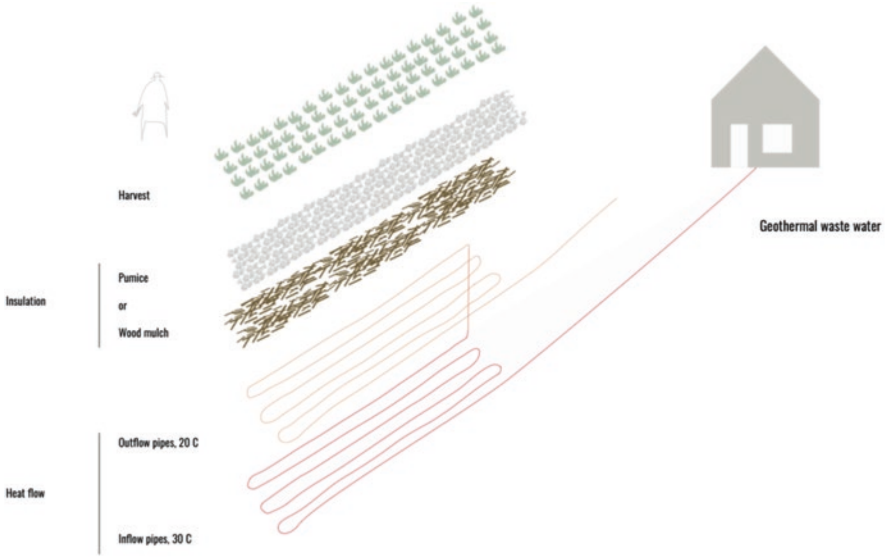


**Fig. 12.5** Impact of low-grade heat and insulation on plant growth. © Vsó Ráðgjöf Ehf (2020). Circular District, Vaxtarhús

Although outdoor cultivation via soil heating cannot substitute frost-sensitive plant cultivation in heated greenhouses, it appears to be significantly cheaper per unit area (Róbertsdóttir, 2020; Vsó Ráðgjöf Ehf, 2020), and it provides a middle ground between costly greenhouse cultivation and low-yield short-season unheated outdoor cultivation (Fig. 12.5).

## 12.4 Circular Economy and Waste Management

### *12.4.1 Pure North Recycling*

Geothermal wastewater could be used to recycle plastic in a circular economy. *Pure North Recycling* is a plastic waste management company based in Hveragerði, 45 km from Reykjavík, with a mission to recycle plastic locally. Icelandic plastic waste is more commonly used to be shipped to mainland Europe or Asia for recycling or incineration. *Pure North Recycling* uses extremely hot geothermal wastewater to clean and recycle the plastic. The temperature of geothermal wastewater in Hveragerði is far higher than the water used elsewhere in Europe and Asia, and it does not require extra energy to be heated up.

Furthermore, local waste management reduces unnecessary shipment costs and carbon footprint from plastic waste by using plastic again locally within a circular economy. According to a comparative Life Cycle Assessment (LCA) of recycling work at *Pure North*, it is estimated that each ton of plastic recycled by *Pure North* saves 0.7 tons of $CO_2$eq and 1.8 tons of oil; in addition, the processing technique reduces additional carbon dioxide of 1.52 $CO_2$eq per ton compared to recycling plastic in Europe or Asia (Pure North project, n.d.). *Pure North* currently recycles 2500 tons of plastic hay-baling waste annually, and the company aims to double its production by 2021. Most prominent Icelandic companies have cooperated with *Pure North* to recycle their plastic. *Pure North* envisions a future where plastic in Iceland is recycled locally over and over in a circular economy, thanks to the abundance of geothermal wastewater.

## 12.5 Circular Food District

### *12.5.1 Vaxtarhús*

The final part of this chapter focuses on the first attempt of the Reykjavík municipality to encourage more circular district design within the neighbourhood. Vaxtarhús is a winning design proposal for a carbon-neutral development in Bryggjuhverfi Vestur district of Reykjavík. The proposal is the result of close collaborations with different partners (VSÓ Ráðgjöf ehf, Reiulf Ramstad Architects AS, MStudio, Sigridur Olafsdottir Grima architects, Íslenskar fasteignir (ÍF), EIK Fasteignafélag and The Agriculture University of Iceland) who comes together to share the knowledge of circular economy within different fields. The district will boast Iceland's first fully circular design, providing a haven for urban farming and dining. The district's design aims to increase the role of urban farming and food security as an integral part of a holistic living ecosystem based on circular principles. The core of the design is on integrated farming systems utilising public and private space, greenhouse development and integration, water use and mitigation, nutrition cycles, compost solutions and energy efficiency design.

The site is located at the centre of one of the most historical industrial sites of the capital area; the presence of two concrete silos is the entrance to the new Bryggjuhverfi Vestur. The design proposal focuses on revitalising the existing silos by giving a new life to serve as a cornerstone for local farming and food services, housing a local food hall for inhabitants and visitors to promote the sustainability and resiliency of the area. The Circular District aims for a holistic circular solution to minimise the negative impacts of construction practices on the climate.

To design such a neighbourhood, different experts from the Icelandic circular food ecosystem got a deeper insight into Iceland's system and gathered knowledge that has been useful from the beginning of the design process. The goal was to design a system within the Circular District that fosters a healthy food ecosystem and creates shared value with circular principles in mind.

The agricultural function design was based on three concepts: On-Site Farming, Neighbourhood Farm Service, and Local Food Sourcing.

The growth area was supposed to be located inside three main areas: Greenhouses, outdoor growing and in a controlled environment agriculture (CEA), transforming the industrial silos into a vertical farm (VAXA FARM, approximately 10x40m silos: 800 cubic meters). The design foresaw three strategies to provide adequate space for on-site farming in greenhouses: a. Rooftop greenhouse on a new building. b. Connect buildings with greenhouses, which will also host a serving area for a restaurant/cafe. c. Expand plot area into School plot.

Core neighbourhood farm services are provided by VAXTARHÚS, which manages agricultural growth areas in residential clusters (greenhouses and outdoor plants) and public spaces. VAXTARHÚS manages School gardens and allotments on the school property and runs an educational program for school children and the public. For food security reasons, carbon footprint, and freshness VAXTARHÚS emphasises supporting regional agriculture production. This is done with agreements with district food and farming producers and suppliers. Regional food is sold in the VAXTARHÚS food store and through Farm Box Schemes that will be delivered to the MAT distribution stations.[2] Information on local food sourcing programs is communicated to the local area and the broader community through The Circular District Digital platform. This information will include saved food miles, reduction of carbon footprint and food security level from regional food availability. One of the central cores of design processes is thermal wastewater management to take advantage of abundant geothermal wastewater in Iceland (Figs. 12.6, 12.7, 12.8).

## 12.6 Concluding Remarks

The driving force behind most Icelandic geothermal implants takes into account the different types of circular economy that could be combined with thermal water waste management.

The functional solutions and circular design are part of policies in geothermal implants; the central part of the challenges is to adopt and integrate a new form of structures that can also act as potential placemaking elements designed to function as recreational and productive areas. Recent projects display examples of mere functional structures – like the VAXTARHÚS, Pure North, Friðheimar and ALDIN Biodome – as well as multifunctional recreational structures – such as Nauthólsvík Geothermal Beach and The Blue Lagoon.

[2] MAT is a sustainable distribution system for online grocery shopping.

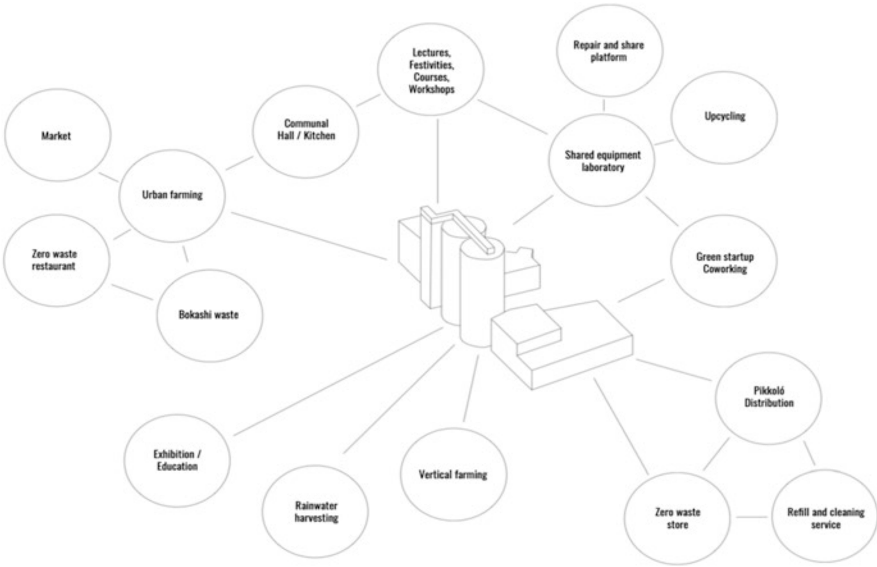


**Fig. 12.6** The circular design for a carbon-neutral development in Bryggjuhverfi Vestur, Reykjavík. © Vsó Ráðgjöf Ehf (2020). Circular District, Vaxtarhús

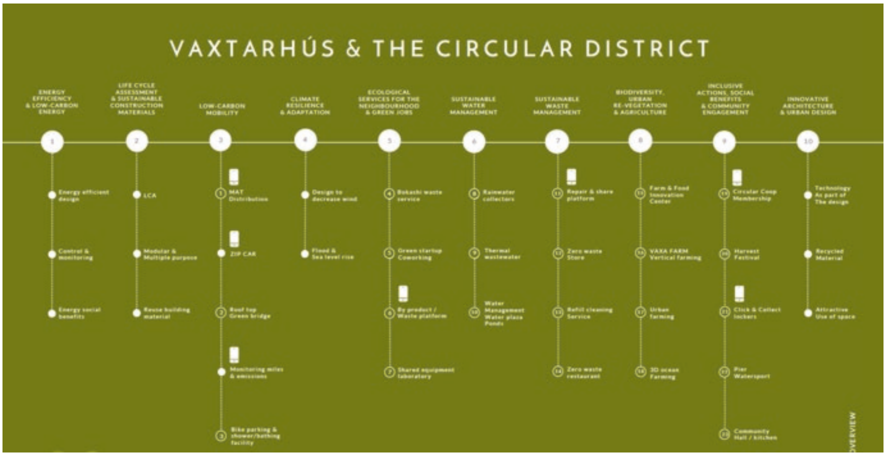


**Fig. 12.7** An overview of the Circular District's core design segments. © Vsó Ráðgjöf Ehf (2020). Circular District, Vaxtarhús

Icelandic geothermal implants are distinct in their holistic wastewater management, and their design is rooted in the culture of "survival", making "habitable" the "last edge of the earth". In the land of Ice and Fire, the design of geothermal implants is a fluid approach that finds new methods to get the best out of a complex inherited nature. It demonstrates the Icelandic ingenuine attitude of *þetta reddast* (it will all work out).


**Fig. 12.8** An overview of the Circular District's design. © Vsó Ráðgjöf Ehf (2020). Circular District, Vaxtarhús

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