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Parameters Affecting Price Valuation of Geothermal Resources

Omar Sigurdsson

HS Orka hf. Brekkustigur 36, IS-260 Reykjanesbaer, Iceland

omars@hs.is

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ABSTRACT

Recent changes in Icelandic laws regarding energy resources such as hydro and geothermal require that the controlling right of the resources to be at all times at the communities or the state. Companies producing electricity in a competitive market from those resources need to rent or pay royalties for the access to utilize them. This has called for a method to determine a fair rent or royalty payment for any given geothermal resource.

A method is proposed and described for determining the yearly payment for a given geothermal resource. A quality factor is introduced so the proposed method could include the different situations found in various geothermal fields. Few of the main cost bearing factors that the resources impose on the utilization are taken into this quality factor. In addition, a minimum reinjection is required depending on steam used, before reinjection starts to discount the payment as a procedure to preserve the resource. With the proposed method the price factors could be set the same for broad types of geothermal resources and utilization. The method is presented as a formula where the yearly payment or rent is divided in to three main charging categories, which are charge for installed power, charge for heat energy and charge for land and other benefits.

1. INTRODUCTION

In 2008 laws were passed in Iceland with the purpose of setting clearer rules regarding ownership of resources in public possession and clarify further the distinction between competitive and concessive operation of the energy companies. The aim was to insure that all the important water and geothermal rights, along with some others, currently in the possession of the state or communities, directly or indirectly, would continue to be in the ownership of these parties. The state, communities and companies in their possession are unauthorized to alienate, directly or indirectly and with enduring way, ownership to rights that could produce more than 7 MW power. The state, communities and companies in their possession are authorized to administer temporary access to these rights for maximum of 65 years at a time. In effect private companies can no longer buy land with utilization rights to these resources. Companies producing electricity in a competitive market from hydro or geothermal resources now need to rent or pay royalties for the access to utilize them. This has called for a method to determine a fair rent or royalty payment for any given geothermal resource.

A brief search was made to look for precedent samples describing the base for royalty payments of resources such as geothermal, oil and mining. Few samples were found both domestic and foreign. A good overview can be found of the policy used by individual states in the USA to determine the royalties for geothermal resources on government own land (see web site). However, only few of the states have active geothermal utilization. Generally the royalty is a ratio of the gross revenue from the primary product (electricity). Other variations are found, but are being turn from with the changes in the Geothermal Steam Act Amendments of 2005. Generally it appears that the royalty is in the range 0.5-2.5% of the gross revenue for the first 10 years of operation and in the range 2-5% after that time. Limited information could be found on royalties from privately own land. Geothermal byproducts such as heat production bear in some cases reduced royalty payment. According to reports from the Bureau of Land Management (BLM) and Mineral Management Service (MMS) was the average royalty in 2004 for geothermal resources on land owned by the federal government 5.3% of the gross revenue from electricity sale from flash plants, 4.7% from dry steam plants and 0.6% from binary plants. Same reports estimate that the world average is about 3.9% of the gross revenue for electricity produced on government owned land (Hance, 2005).

Information from other foreign countries is scarcer but in Europe and Australia it appears that the royalty ratio is set around 2.5% of the gross revenue from the primary product, usually electricity (EGEC, 2007). In Australia the reference is in many cases to the wellhead value of the product and resembles in that way royalty for oil production (see PIRSA). In some countries the royalty payment has been used to control the utilization of the resources. In all the foreign references the geothermal resources have been treated similar to mining resources and not as renewable resources.

From Iceland are hardly any precedent samples. This issue has though been looked at and the best example is from a memorandum by Stefansson (2000) regarding inquiry for utilizing a geothermal resource on governmental land. Stefansson suggests that the rent or royalty for a geothermal resource should promote a sensible utilization of the resource. The payment will depend on the available knowledge on the resource but on the other hand a decision on utilization will hardly been taken until a reasonable knowledge has been obtained. The payment should not depend on the product made from the utilization of the resource but should rather be on the produced heat energy. Furthermore, he concluded that the lessee should pay a minimum fixed rent which should be a ratio of the final rent. The fixed part of the rent should prevent or discourage companies to hold utilization rights for long time without actually developing the resource. This can be expressed with the following equation:

$$\text{Royalty} = c_1\, N + c_2\,(E_p - E_i) \tag{1}$$

The equation consists of two parts, royalty for power and for energy. It includes a discount for the operator for preservation of the resource but does not consider the quality of the resource for utilization.

Sigurdsson.

In a study by Stefansson (2004) a comparison is made with royalty paid for hydro-rights. His finding is that royalty for hydro was around 0.7% of the revenue generated by hydro-electric production. He also concludes about a reasonable single payment value for the utilization rights. He divides the areas into less and fully investigated areas where the less investigated areas have lower royalty ratios. For royalty calculated from the dividend the ratio was in the range 1-5%.

In 2006 the Icelandic state made an agreement with Landsvirkjun (National Power Company) for utilizing the geothermal rights at Krafla, Bjarnarflag and Namafjall for generating up to 350 MW_e. In the agreement the royalty is referred to either as a power charge or an energy charge which are defined as follows:

$$\text{Power charge} = 0.2\,\mathrm{A}\,8000\,p \qquad (2)$$

$$\text{Energy charge} = E\;p \qquad (3)$$

The power charge is referred to 8000 hours up time of the plant and comes in before production commences. Notable is also the fraction 0.2 which appears to have reference to earlier work of Stefansson (2000) making it only a fraction of the final royalty. Furthermore, the power charge is a minimum base charge while the energy charge takes over when it becomes higher than the power charge after electrical generation has commenced. No direct consideration is made for the quality of the resource or its preservation in equations 2 and 3, but it could be negotiated into the price factor. The agreement abdicates any additional royalty for byproducts that could lead off the primary production.

2. GEOTHERMAL RESOURCES

A geothermal resource exists due to a relatively shallow heat source embedded in the Earth’s crust that has heated up a volume of rock mass surrounding it. Therefore, the geothermal resource is a relatively shallow heat anomaly in the crust where the geothermal gradient is much higher than the normal gradient found elsewhere. Geothermal utilization is based on harnessing this heat energy that is stored in the geothermal systems. To bring the heat energy up to the surface a carriage medium is needed which is in most instances the fluid found within the porous rock in the system. However, the quality or suitability of the fluid for production can be very different from one geothermal system to another. It will depend on how the geothermal system originated and matured in the geological environment of the system.

In general, the dissolved solid content in geothermal fluid increases with increasing temperature in the geothermal system. The dissolved solid content will also depend on the origin of the geothermal fluid, be lower if of meteoric origin and higher if originating as seawater. Associated with the fluid are also gases that affect its quality for utilization. The gases usually follow the steam phase of the fluid when on surface and are mostly non-condensable so they need to be dealt with in the production line. The enthalpy of the fluid controls the choice of layout for the generation plant. Fluid with temperature over 200°C can be used in flash plants while fluid in the temperature range 200-100°C can be used in binary plants. Other and lower temperature ranges can be used for other applications.

The porosity in the rock holds the geothermal fluid, but commonly over 85% of the stored heat energy is in the rock matrix. It is therefore more likely that the fluid in the system will be completed long before the heat is completed. To sustain and prolong the utilization of the system additional fluid is needed. It can happen in two ways, by natural recharge or by injection. If the natural recharge is high no extra injection may be needed to hold moderate drawdown but if not then reinjection may be required. Then it would be best to inject the liquid phase of the separated fluid, possibly with some mixing of condensate. However, the separated liquid may not be suitable for injection due to high mineral concentration. Possibly it could be used after some handling but that will involve additional cost. If it cannot be injected then it has to be disposed of in another way with appurtenant cost while at the same time it can diminish the preservation of the geothermal resource.

Productivity of a geothermal system depends on the permeability of the geological formations and how open the fracture net is that connects reasonably large portions of the system together. The permeability controls the fluid flow between voids in the rock matrix. However, without the net of fractures the permeability would generally be too low for economical utilization of system. Therefore, wells are targeted to the fracture zones in hope for higher productive wells, but the fracture permeability is different as the formation permeability. The higher the wells productivity the fewer wells are needed for a given production and vice versa. Wells productivity is as such a certain measure on one of the geothermal systems properties that affects its utilization.

3. QUALITY OF GEOTHERMAL RESOURCES

Several parameters affect the suitability of a geothermal resource like for generation of electricity. The following can be mentioned:

- Quality of the geothermal fluid, affected by such as concentration of TDS and gases.
- Productivity of wells and convertibility of the fluid to the end product.
- Preservation of the resource.
- Cost for disposing of the geothermal fluid.
- Access to cooling water.

For fairness in contract negotiations for royalty or rent for utilizing the resource, the most important parameters should be taken into consideration. That can be done by defining a quality factor that would reflect the effects of these parameters. Parameters considered here are the total dissolved solids concentration, mass fraction of gas in steam and field average well productivity.

Figure 1 is an attempt to access the increased difficulty in the utilization process associated with the increasing content of dissolved solids (TDS). The TDS content depends some on the origin of the geothermal fluid. With its increased concentration the risk of scaling in wells or equipment increases. This in turn increases the operating cost and reduces the life span of equipment. To minimize the scaling risk, separation pressure may need to be raised which lowers the amount of steam obtained from a unit of mass produced. Therefore, the quality and value of the fluid is highest for the lowest TDS content and becomes less with increasing TDS.

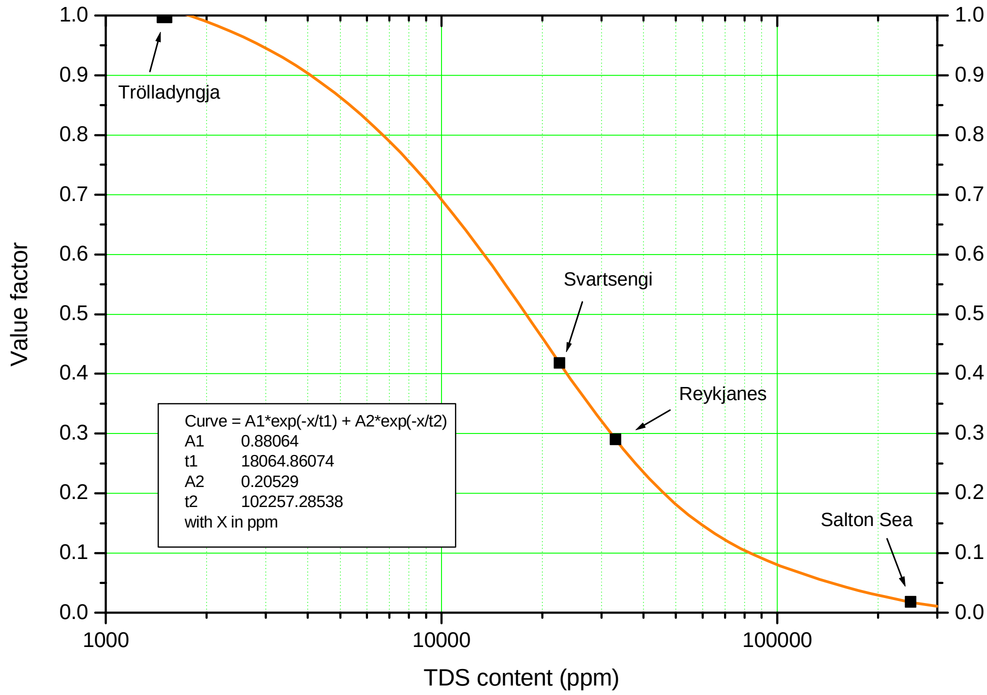

Figure 1: Change in value with TDS concentration.

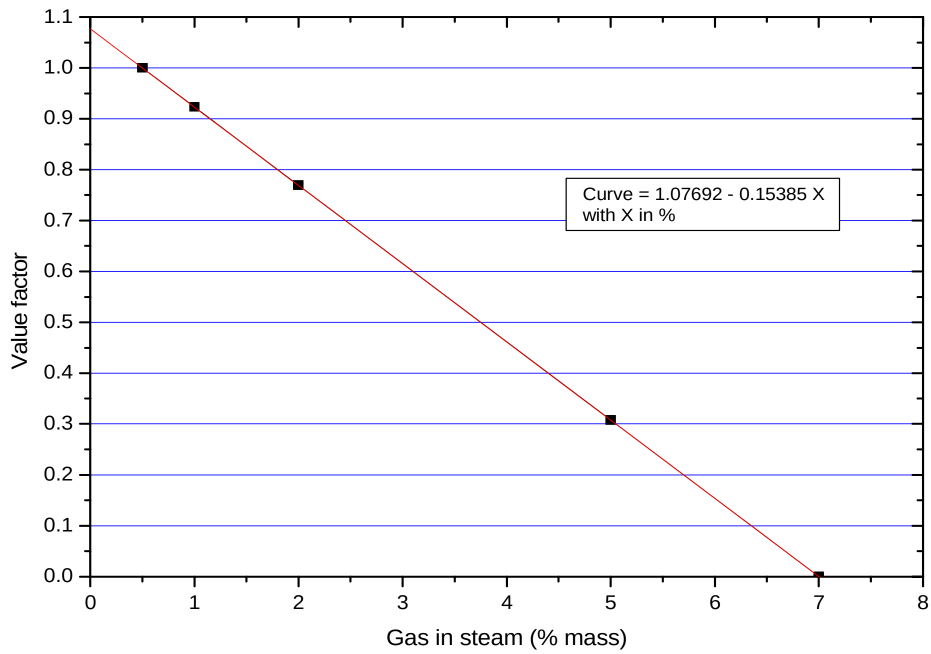

Figure 2: Change in value with gas mass fraction in steam.

Most Icelandic geothermal systems have low TDS content; many have less than 2,000 ppm (Nesjavellir, Trolladyngja). Some have a moderate amount like Svartsengi field where the TDS is 22,500 ppm and the Reykjanes field with around 33,000 ppm. There the geothermal fluid has the same salinity as seawater. This moderate amount of TDS poses some difficulties for the production so the value is reduced. However, resources with very high TDS are produced for electrical generation as at the Salton Sea area in the USA where TDS is as high as 240,000 ppm. There the fluid needs treatment so it is used to set the lower limits for its value. The curve connecting the points in Figure 1 could be drawn differently, but this shape was considered applicable for this large span.

Icelandic geothermal systems commonly have relatively low mass fraction of gases in the steam. Non condensable gases reduce the efficiency of the turbines used for electrical generation. Gas fraction 0.5-1% is manageable, but higher fraction starts to reduce the efficiency or calls for a different generating plant design. When the gas mass fraction becomes higher than 2%, it becomes difficult to operate flash-turbine plants. Plants running back pressure turbines can be operated even though the gas fraction approaches 5%. For higher gas fractions one is usually left with binary turbines. Figure 2 shows how the value curve could look like for the mass fraction of gases in steam.

Sigurdsson.

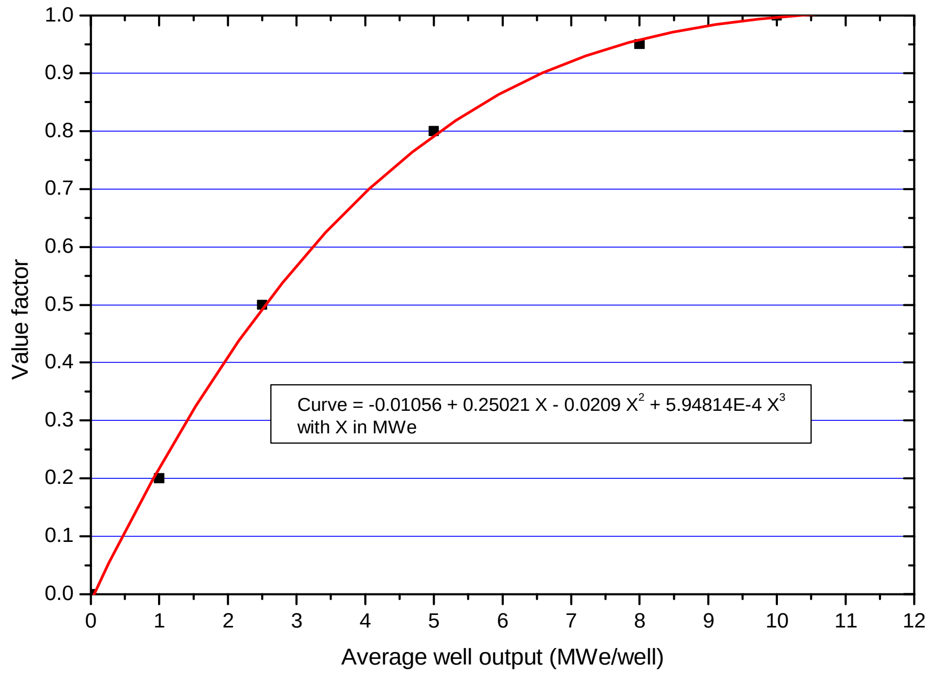

Figure 3: Change in value with average well output.

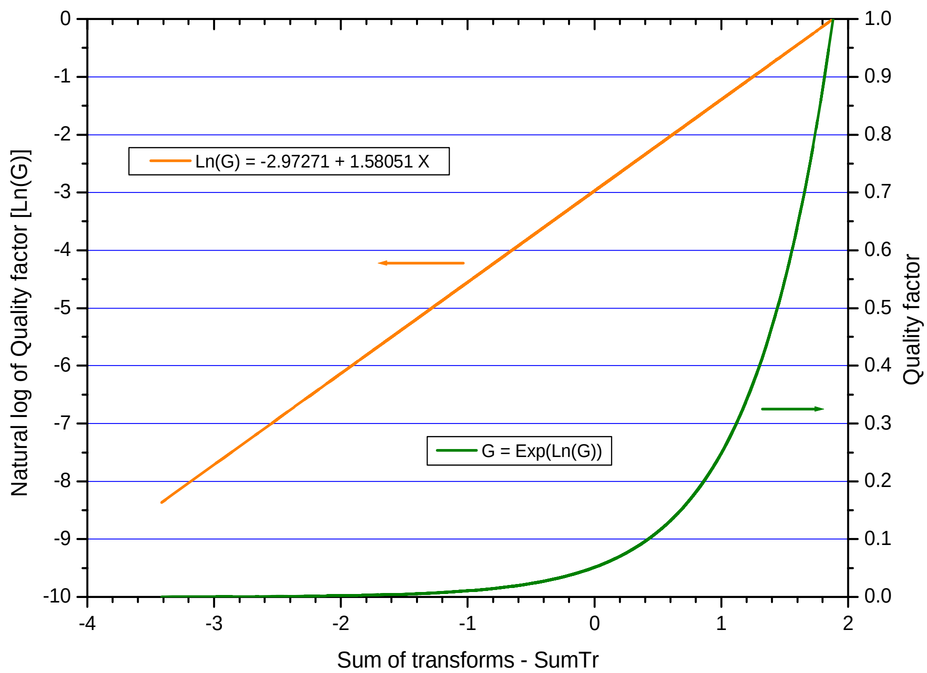

Figure 4: Change in value with resource quality.

Figure 3 depicts how the estimated value increases with increasing average productivity of wells tabbing a given resource. In a review on about 30 geothermal resources all over the world, Stefansson (1992) concluded that the average power output for high enthalpy wells in these resources was 4.2 MW_e and the span was 1-10 MW_e. A well with a power output at or higher than this average has to be considered good, but if it falls below this average the well value can reduce rapidly. Stefansson (1992) showed that for every field there existed a certain learning curve, but the curve approached some characteristic average for the field when the number of wells drilled got up to 10 or higher.

One could count for other parameters than these threes, but here it is assumed that their impact is less. The above parameters can be combined into a quality factor that should reflect in the value of the resource (Sigurdsson, 2008). The resulting function is shown in Figure 4, but it is obtained by combining the functions given in Figures 1 to 3 by non-parametric approach (Xue et al., 1997). The functions for the parameters transform (_Tr); their sum (SumTr) and back transform to the quality factor are given as:

$$Ln(TDS\_Tr) = -0.11353[Ln(TDS)]^2 + 1.76682 Ln(TDS) - 6.25056 \quad (4)$$

$$gas\_Tr = -0.00408(gas)^4 + 0.0441(gas)^3 - 0.17443(gas)2 + 0.14168(gas) + 0.58409 \quad (5)$$

$$Ln(mwe\_Tr) = 0.10494[Ln(mwe)]^2 + 0.66104\,Ln(mwe) - 0.3262 \quad (6)$$

$$SumTr = Ln(TDS\_Tr) + gas\_Tr + Ln(mwe\_Tr) \quad (7)$$

$$Ln(G) = 1.58051(SumTr) - 2.97271 \quad (8)$$

$$G = \exp(Ln(G)) \quad (9)$$

One should note that if some of the curves in Figures 1-3 are changed then the transform functions will also change. The ranges for these functions are 1,750-300,000 ppm for TDS, 0-7% gas fraction and 0-11 MWe for well average power output. If the concentration of TDS becomes less than 1800 ppm then the Ln(TDS_Tr) can be fixed at 0.627.

4. PROPOSED ROYALTY FORMULA

Different methods can be used to determine the royalty or rent for utilizing a geothermal resource. However, it is the opinion of the author that the determination of royalty should bear the resource in mind, its preservation and quality regarding the end product. The quality affects the cost of utilizing the resource while its preservation prolongs its longevity. With that in mind a formula on the following form is proposed:

$$\text{Royalty} = 0.2c_1 A + c_2 [G E_p + E_a - E_i] + c_3 F \quad (10)$$

The first part of the formula is a charge for installed power, the second for produced energy and the third for land uses and access to cooling water. The constant 0.2 could be included in the constant c_1, but is kept there as a reminder and reference to earlier works as by Stefansson (2000). The idea is that the power charge is basically a minimum charge and that it should not weight high in the total charge. The quality factor (G) comes with the produced heat energy (E_p). Then there is an add-on charge (E_a) to encourage a minimum preservation of the resource. That could correspond to injection of the steam condensate as its quality should be good enough for injection. Preservation with injection (E_i) reduces the charge as the resource longevity is increased and possibly the same fluid is circulated few times between producers and injectors.

In the early development of a resource the quality factor may have to be reevaluated but should generally be relatively stable for the resource. The price factors could also be determined once and then fixed to the price trends of power, energy and land.

As an example to determine royalty one can take a field with similar parameters as Reykjanes; TDS 33,000 ppm, gas mass fraction in steam 1% and average well output for the installed 100 MWe plant about 8.3 MWe/well. This will result in:

Ln(TDS_Tr) = -0.15757

gas_Tr = 0.59136

Ln(mwe_Tr) = 0.60275

SumTr = 1.03654

G = 0.26

About the same result for the quality factor would be obtained by reading the value factors from Figures 1-3 and multiplying them together. Given the additional information that produced mass is 730 kg/s with enthalpy 1390 kJ/kg, used steam is 170 kg/s and the temperature of the condensate is 40°C (167 kJ/kg). Assuming up time of 8000 hours, no injection and the following price factors put into equation 10:

c_1 = 0.5 MIkr/MW$_e$ or 500 Ikr/kW$_e$

c_2 = 0.015 Ikr/kW$_t$h

c_3 = 0

Royalty = 0.2*0.5(MIkr/MWe)*100(MWe) + 0.015(Ikr/kW$_t$h)*8000(h)*[0.26*1390(kJ/kg)*730(kg/s) + 167(kJ/kg)*170(kg/s)-0] + 0

Royalty = 10(MIkr) + 35.1(MIkr) + 0 = 45.1 MIkr

5. CONCLUSIONS

The finding from looking for examples of royalty determinations indicates that it generally lies around 2.5% of the gross revenue for the primary product (electricity). A formula is presented to determine the royalty for a geothermal resource that includes charges for installed power, net energy produced from the resource and land benefits. The installed power charge is intended to be a minimum rent. The charge for heat energy produced is adjusted by the quality factor which includes parameters that affect the cost of producing the resource. Preservation of the resource is rewarded.

In the presented formula the price factors are connected to the gross revenue of the primary product, here electricity. As the quality factor incorporates the main parameters affecting the valuation of the resource, the price factors could be determined independently of the geothermal field. As such the price factors could be fixed for broad range of resources and used to determine royalty for geothermal fields with either or both electrical generation and production of hot water for space heating.

NOMENCLATURE

A = installed power capacity (kW$_e$)

c_1 = price factor for installed power (Ikr/kW$_e$)

c_2 = price factor for heat energy (Ikr/kW$_t$h)

c_3 = price factor for land (Ikr/km^2)

E = yearly electrical energy produced to the grid (kW$_e$h)

E_a = yearly add-on heat energy (kW$_t$h)

E_i = yearly injected heat energy (kW$_t$h)

E_p = yearly produced heat energy (kW$_t$h)

F = area of land (km^2)

G = quality factor, dimensionless (0-1)

Sigurdsson.

N = maximum allowable power production from a resource (kW_e)

p = production price factor (Ikr/kW_eh)

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