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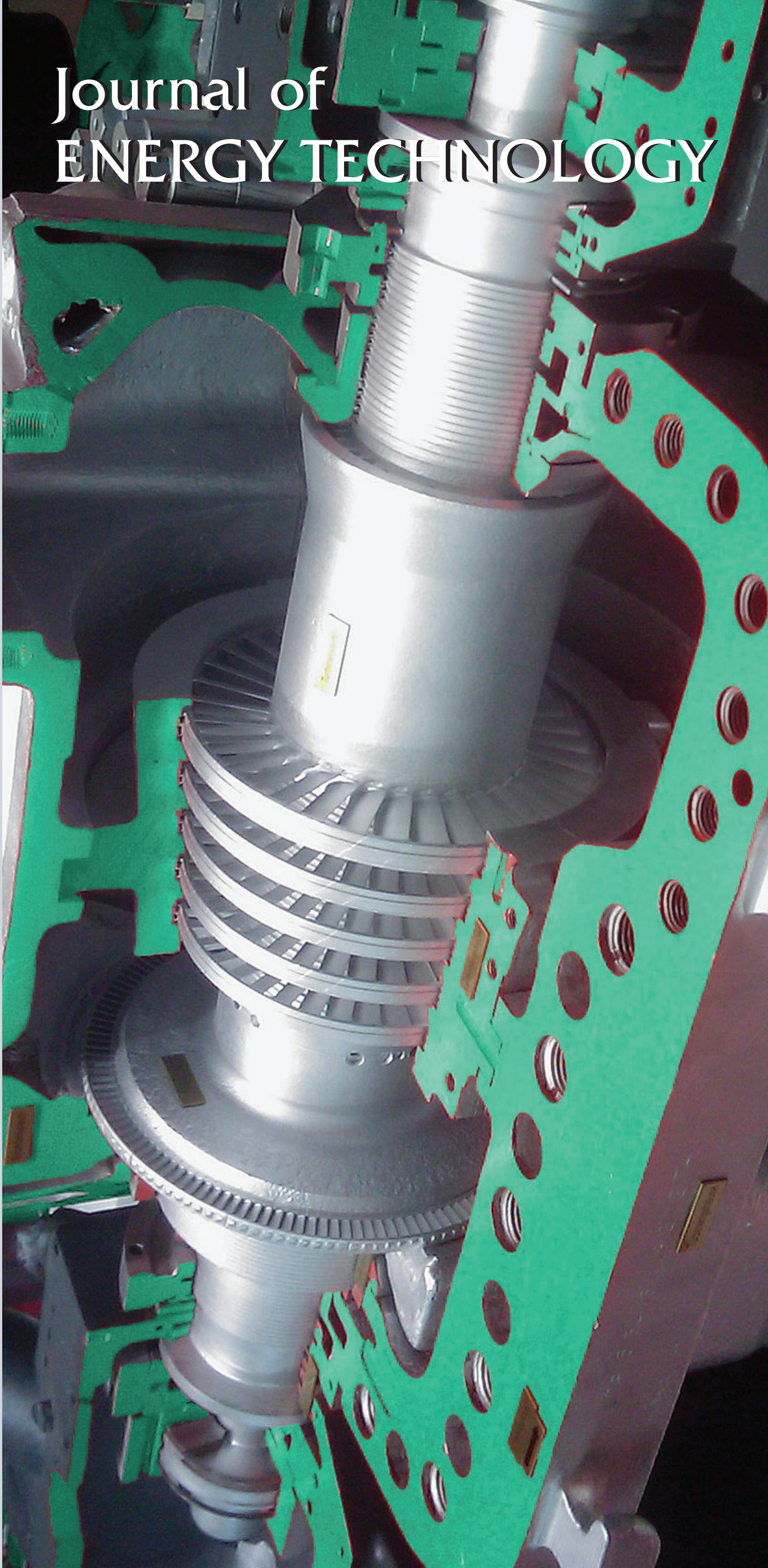

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Izdajanje revije JET finančno podpira Javna agencija za raziskovalno dejavnost Republike Slovenije iz sredstev državnega proračuna iz naslova razpisa za sofinanciranje domačih znanstvenih periodičnih publikacij / The Journal of Energy Technology is co-financed by the Slovenian Research Agency.

Odkupne cene električne energije, proizvedene iz OVE virov in SPTE v Sloveniji v letu 2014

Borzen, organizator trga z električno energijo d.o.o. je izdal dokument *Določanje višine podpor električni energiji proizvedeni iz OVE in SPTE in višine podpor v letu 2014,* ki veljajo za elektrarne, ki vstopijo v sistem podpor. Opredeljen je bil z novim Energetskim Zakonom (veljaven od 22. 3. 2014). Dokument predstavlja neuradni izračun višin podpor za leto 2014 (uradni izračun opravi Javna Agencija RS za energijo). Splošno je razviden padec povprečnih odkupnih cen od leta 2009, ko je le-ta znašala 65 €/MWh, na 43,31 €/MWh, ki velja v letošnjem letu. To pomeni znižanje odkupnih cen na 66,6 % cene iz leta 2009. Navkljub padcu cen veliki proizvajalci električne energije v Sloveniji tarnajo, da te subvencije zajedajo njihov dobiček in tako posredno ogrožajo delovna mesta na področju energetike. Ponovno se torej odpira stara dilema ali subvencionirati proizvodno ali investicije na področju OVE in SPTE virov, seveda v manjših enotah.

V kolikor v Sloveniji resno mislimo na pot večjega koriščenja OVE virov, potem seveda ni dileme, da so subvencije potrebne kot vzpodbuda potencialnim investitorjem. Vendar samo to ne bo dovolj. Hkrati bi morali posodabljati električno omrežje v smeri razvoja pametnih omrežij, ki lažje (ustrezno) vključujejo in upravljajo z manjšimi proizvodnimi enotami. Tu pa seveda trčimo ob problem investicijskega denarja, ki ga praviloma za omrežje vedno zmanjka. Investicija je visoka, povrnitev vloženih sredstev pa dolgoročna. To seveda ni zanimivo za investitorje, ki želijo čim prej in čim bolje povrniti vložena sredstva.

V vmesnem obdobju, na prehodu iz ogljične v nizko-ogljično družbo, pa seveda brez velikih trajnostnih energetskih postrojenj še ne bo šlo.

Andrej PREDIN

The prices of electricity produced from renewable sources and cogeneration in Slovenia in 2014

Borzen, the electricity market company, has issued a report entitled *Determination of the level of support for electricity generated from RES and CHP and the level of support in 2014*, which applies to plants in the support system defined by the new Energy Act (in force since March 22, 2014). This document presents an informal calculation of the level of support for the 2014 (the official calculation is performed by Public Agency for Energy). It shows that there has been a decrease in average purchase prices since 2009, when it stood at €65/MWh, to €43.31/MWh in 2014, which means a reduction in feed-in tariffs to 66.6%. Despite the fall in prices, large producers of electricity in Slovenia complain that subsidies have parasitic effect on their profits and thus indirectly threaten jobs in the energy sector. Therefore, once again, the old dilemma of whether to subsidize production or investment in the field of RES and cogeneration sources has been raised.

If in Slovenia we intend to continue on the path of greater use of renewable sources, then, of course, the dilemma is that subsidies are necessary as an incentive to potential investors. However, they will not be enough. The incentives should simultaneously update the electricity grid towards the development of smart grids, which are better (properly) included and manage small production units. Here, of course, is the issue is the problem of investment money which, as a rule, the network still handles. The investment is high, and return on investment is long-term. This is not interesting for investors who want to recover their funds invested as soon as possible.

In the meantime, the transition from a carbon society in a low-carbon society will not work without major sustainable energy plants.

Andrej PREDIN

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CURRENT-TEMPERATURE ANALYSIS OF THE AMPACITY OF OVERHEAD CONDUCTORS DEPENDING ON APPLIED STANDARDS

ANALIZA TOKOVNO-TEMPERATURNE PREOBREMENLJIVOSTI VODNIKOV DALJNOVODOV GLEDE NA UPORABLJENE STANDARDE

Ivica Petrović[ℜ], Hrvoje Glavaš, Željko Hederić

Keywords: Transmission capacity, Ampacity, Conductor Temperature, Overhead Power Line

Abstract

The opening of the electricity market is accompanied by new market participants whose requirements need to be fulfilled in order for the electricity market to function. To do so, transmission capacity is of significant importance. As the building of new overhead lines is an expensive and long-term investment, increasing the transmission capacities of existing lines is an unavoidable necessity. The transmission capacity of overhead power lines is commonly determined by limitations on the conductor's temperature, characterized by its ampacity. The conductor's temperature, and therefore the ampacity, is dependent on weather conditions. This fact enables increasing the transmission capacity according to calculations based on current weather conditions and forecasts, as opposed to static and conservative values.

This paper discusses the application of different standards and comparison of results for transmission capacity value, with particular reference to Croatian legislation on transmission overhead power lines. Calculation of sensitivity on input parameters is also examined because of the changes in the weather that change transmission capacity. As an extreme case of unfavourable weather

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conditions, an example is given of transmission capacity value trends during the hottest recorded day Croatia. The conclusion is that increases of the transmission capacity on particular power lines is possible but, for the safe and secure operation of the transmission grid, a seasonal regime of operation or ampacity zones depending on the time of the year could be made.

Povzetek

Odpiranje trga z električno energijo spremlja vstop novih udeležencev na trg, kateri morajo izpolniti določene zahteve, da trg z električno energijo lahko nemoteno deluje ob upoštevanju prenosne zmogljivosti prenosnega omrežja. Gradnja novih daljnovodov je finančno zahtevna ter predstavlja dolgoročne naložbe in je žal neizogibna zaradi želenega povečanja prenosnih zmogljivosti obstoječih daljnovodov. Maksimalna tokovna zmogljivost in temperatura vodnikov omejuje zmogljivost prenosa daljnovodov. To dejstvo omogoča povečati prenosno zmogljivost v skladu z izračuni, ki temeljijo na trenutnih vremenskih razmerah in napovedih, v nasprotju s statičnimi in klasičnimi vrednostmi.

Ta članek obravnava uporabo različnih standardov in primerja rezultate vrednosti prenosnih zmogljivosti prenosnih daljnovodov z upoštevanjem hrvaške zakonodaje. Analiziran je vremenski vpliv na vhodne parametre, kar vpliva na prenosne zmogljivosti in posledično na občutljivost izračuna. Kot ekstremni primer neugodnega vremenskega vpliva je v analizi zajet tudi najbolj vroč dan na območju hrvaškega prenosnega sistema. V zaključku dela je predstavljeno, da je možno povečati zmogljivosti prenosnega omrežja oziroma posameznih daljnovodov, vendar za varno in zanesljivo obratovanje omrežja je potrebno upoštevati sezonski režim delovanja.

1 INTRODUCTION

The transmission capacity of electric grid elements is significantly defined by deterministic safety criteria. Therefore, certain categories of failures or breakdowns are of great importance for the assessment of an electric grid and electric power system safety. If a physical quantity (allowed current, voltage, etc.) exceeds the defined and allowed range of values in the case of failure, the situation before the fault is considered to be unsafe. According to the safety criteria, the grid configuration must be designed in such a manner that it is able to ensure, in all operating conditions, that the failure of any power line does not lead to operational restrictions of its own and/or neighboring regulation areas. For the same reason, regulations for power lines treat and determine the highest ampacity of overhead conductors in individual systems.

From that, the timely determination of the available transmission capacity must follow, as is the most urgent task to be perform in order to increase both the safety and efficiency of the electricity system. Due to a significant number of cases in which the transmission capacity is determined by the highest allowed conductor temperature, such determination or calculation of the conductor temperature during operation is becoming increasingly important. Therefore, the conductor temperature values are calculated with regard to regulations and all factors that affect heating and cooling. Specific research is conducted on the mathematical impact of each factor on the determination of the conductor temperature calculation.

2 VALID STANDARDS IN CROATIA FOR CALCULATION OF AMPACITY IN OVERHEAD CONDUCTOR

Designing overhead power lines in Croatia is subjected to the Ordinance of technical standards for the construction of overhead power lines of nominal voltage from 1 kV to 400 kV (Croatian Official Gazette (COG) 53/91, 24/97). The valid ordinance is taken from the Official Journal of SFRY 65/88 in which the conductors and protecting wires are calculated for a range of temperatures from -20°C minimum to +40°C maximum, and for the temperature at which there is an additional load, i.e. -5°C. Article 16 states that the cross section of the conductor lines must be large enough that the overall temperature of the conductor due to the heating from the current does not exceed +80°C, whereby the calculation is conducted with an ambient temperature of +40°C. The article remains unchanged, apart the amendment in 1997 for classic conductor ropes, while for special conductors it allows exceeding the earlier specified conductor temperature if there is proven mechanical stability for a specific conductor. The final result of the maximum conductor temperature corresponds to the most adverse weather conditions, i.e. a small or negligible influence of wind (up to 0.6 m/s) and continuous ambient temperature of +40°C. The value of ampacity determined by this method, in most cases, even in the summer under maximum temperatures, remains below the possible ampacity limit with regard to the temperature limit and regulated safety heights, COG No. 24/97, [1].

3 CALCULATION OF TEMPERATURE ACCORDING TO THE IEEE STD 738-2006

Calculation of the temperature of bare, non-insulated overhead power lines is made with various methods that serve for the calculation of heat transfer and allowed current load of transmission power lines. The mathematical basis of the calculation used is the House and Tuttle method altered and adjusted according to the ECAR (East Central Area Reliability). The method takes into account all the relevant weather factors (influence of the sun and wind) without simplifications, which are made in some other calculations, IEEE [2].

The conductor temperature at a specific location is a function of more variables that have different impacts on the calculation. In the first place, there are weather conditions and their variability in space and time. Other important factors are solar flux, power line orientation in relation to the position of the sun and the direction of the wind motion, the type of the terrain (hilly, forested, etc.), cross-section and the percentage of aluminum in the cross-section, characteristics of materials including steel core, conductor geometry and 'air pockets', current, connected equipment, the density and viscosity of air, surface and external conditions (coefficient of emission and absorption) and corrosion, IEEE [3].

Potentially the greatest mistake possible in the temperature calculation involves a variable that takes into account direction and wind motion. This is because the wind motion is subjected to frequent changes. In the upper atmosphere, wind motion is relatively laminar, but closer to the surface, due to the influence of the terrain and the thermal effects, the motion of the wind becomes turbulent. Therefore, it is necessary to distinguish the still air flow from the turbulent air flow. The House and Tuttle method uses two different equations for forced convection or heat transfer with large air flow. Since the turbulence begins at a certain wind speeds and reaches its peak at higher speeds, the transition from one curve to another is a curve, not a discontinuity. A single value is selected as a suitable value for the calculation of permissible conductor loads; the individual value of transfer results in a discontinuity of current, when this value is reached. Therefore, to avoid this discontinuity, which occurs in House and Tuttle method, ECAR makes a change from still air motion into forced, turbulent air flow at the point or place where the curves are the result from the crossing of two equations (4.1 and 4.2).

This method is primarily intended for calculating thermal values at a fixed state and transient occurrences, and conductor temperatures at fixed, constant weather conditions. In the given circumstances of widely available computers, the method for calculation bypasses certain simplifications, which can be recommended when speed or complexity of calculation, is of great importance. Weather conditions often vary along power lines; therefore, the temperature of the conductor varies from one section to another of the same power line. The proper evaluation and calculation of the conductor temperature via IEE Std 738-2006 should take into account local weather conditions along the sections of the power line.

3.1 Calculation at fixed (constant) state

If there is data available for the maximum temperature of a non-insulated, intertwined conductor (T_c) and weather parameters for constant (unchanging) conditions ($V_{w,}$ $T_{a,}$ etc.), it is possible to calculate heat losses due to convection and radiation (q_c and q_t), gain of heat by insolation (q_s) and conductor resistance $R(T_c)$ using the equations in the third chapter.

Corresponding conductor current (I), which produced this temperature under these weather conditions can be found from the heat balance equation of an unchanging state, according to Equation 3.1. While this calculation can be done for each conductor temperature and under all weather conditions, the maximum allowed temperature of the conductor (e.g. 75°C to 150°C) and moderate weather conditions (e.g. 0.6 m/s to 1.2 m/s wind speed, 30°C to 45°C in summer weather conditions) are often used to calculate the thermal values of conductors at a constant state.

$$q_c + q_r = q_s + I^2 \cdot R(T_c) \qquad (3.1)$$

$$I = \sqrt{\frac{q_c+q_r+q_s}{R(T_c)}} \qquad (3.2)$$

Since heat losses by radiation and convection are not linearly dependent on the conductor temperature, the heat balance equation (3.2) yields conductor temperature expressions for current and weather variables by iteration, i.e. by taking into account electrical current of the conductor:

a) Conductor temperature is assumed,

b) Corresponding heat losses are calculated,

c) Conductor current that generates this temperature is calculated according to Equation 3.2,

d) Calculated current is compared with given conductor current,

e) Conductor temperature is then increased or decreased, until the calculated current does not reach the set current.

3.2 Calculation at transient state

Thermal evaluation of a transient state is regularly calculated by repeating the previous calculations $T_C(t)$ in the range of I_f values, and then selecting I_f value, which causes the conductor temperature to reach its maximum value in a given time. The temperature of the overhead power line is constantly changing, in accordance with changes of the current and the weather conditions. It is assumed that the weather parameters (speed and direction of wind, ambient temperature, etc.) are not changed and that every change of current is limited by a gradual step change, from the initial current Ii to the final current If, as shown in Figure 3.1. Shortly before the step or gradual change of current ($t=0^-$), it is assumed that the conductor is in thermal equilibrium, i.e. that the sum of the heat produced by ohmic losses and heat of the sun is equal to the heat loss by convection and radiation, [10].

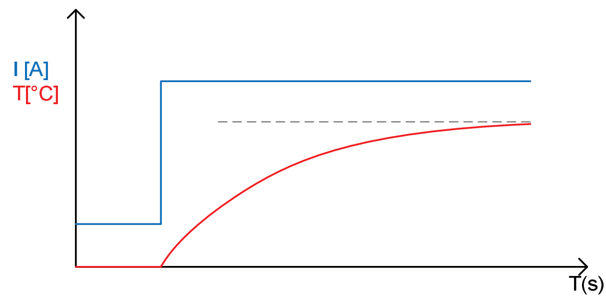

Figure 1: *Gradual, step change of the current from the initial to final current*

Immediately after the gradual, step change of the current ($t=0^+$), the conductor temperature is unchanged (as conductor resistance and heat losses due to convection and radiation), but there is an increase in heat generation due to ohmic losses. Therefore, at moment $t=0^+$ the conductor temperature begins to increase, the increase is given in the heat balance equation for transient state (3.3), as follows:

$$\frac{dT_c}{dt} = \frac{1}{mC_p}\left[R(T_c) \cdot I^2 + q_s - q_c - q_r\right] \tag{3.3}$$

that is

$$q_c + q_r + mC_p\frac{dT_c}{dt} = q_s + I^2 \cdot R(T_c) \tag{3.4}$$

After a period of time, Δt, the conductor temperature increases with temperature change, ΔT_C. Increased conductor temperature leads to greater heat losses due to convection and radiation, and a greater ohmic resistance of the conductor due to increased heat generation. The conductor temperature continues to rise from Δt to 2Δt, but with a smaller increase. After a large number of such time intervals, the conductor temperature approaches its final temperature of constant state, T_f.

The accuracy of the iterative calculation of the transient state requires that the set time of the step or gradual change is sufficiently short compared to the thermal time constant. It is always prudent to repeat the calculation with a shorter interval of change, in order to check the change of the calculated values.

4 EQUATIONS FOR CALCULATION OF THERMAL VALUES (STATES) AND RESISTANCE OF THE CONDUCTOR

Previously, equations for the thermal equilibrium of the fixed state and transient state from 3.1 to 3.4 have been given. Heat losses due to forced convection is described in Equation 4.1, which is used for weak winds, while Equation 4.2 is used for high-speed winds [9].

$$q_{c1} = \left[1{,}01 + 0{,}0372 \cdot \left(\frac{D \cdot \rho_f \cdot V_w}{\mu_f}\right)^{0.52}\right] \cdot k_f \cdot K_{angle} \cdot (T_c - T_a) \tag{4.1}$$

$$q_{c2} = \left[0{,}0119 \cdot \left(\frac{D \cdot \rho_f \cdot V_w}{\mu_f}\right)^{0.6} \cdot k_f \cdot K_{angle} \cdot (T_c - T_a)\right] \tag{4.2}$$

At any wind speed, the higher value of the two calculated heat losses due to convection is taken. The loss of heat due to transmission by the wind is multiplied by the wind movement factor, where φ is the angle between the wind direction and axis of the conductor (see Equation 3.3).

$$K_{angle} = 1.194 - cos\varphi + 0{,}194 \cdot \cos(2\varphi) + 0{,}368 \cdot \sin(2\varphi) \tag{4.3}$$

As an alternative, wind direction factor can be expressed as a function of the angle β between the wind direction and perpendicular to the conductor axis. This angle is the complement to φ ; the wind direction factor then changes according to equation 4.4.

$$K_{angle} = 1 - 1.194 - sin\beta - 0{,}194 \cdot \cos(2\beta) + 0{,}368 \cdot \sin(2\beta) \tag{4.4}$$

When there is no air flow and the wind speed is 0 m/s, heat losses are the result of natural convection and are shown in equation 4.5.

$$q_{cn} = 0{,}0205 \cdot \rho_f^{0.5} \cdot D^{0.75}(T_c - T_a)^{1.25} \tag{4.5}$$

The aim is to prove that at low wind speeds cooling due to the convection should be calculated using the vector sum of the wind speed and the ‘natural’ wind speed. However, using only the higher heat losses is recommended due to forced and natural convection at low wind speed instead of their vector sum, because it is moderate, IEEE [2].

For forced and natural convection, density, ρ_f , viscosity, μ_f, and the thermal conductivity coefficient, k_f , of the air are taken from Table 2, or their values are calculated according to Equations 5.2 to 5.4, at T_{film} :

$$T_{film} = \frac{T_c + T_a}{2} \tag{4.6}$$

Heat losses due to radiation are given in Equation 4.7:

$$q_r = 0{,}0178 \cdot D \cdot \varepsilon \cdot \left[\left(\frac{T_c+273}{100}\right)^4 - \left(\frac{T_a+273}{100}\right)^4\right] \tag{4.7}$$

Gain of heat due to insolation is calculated with Equation 4.8, for which the data is used from Tables 3, 4 and 5:

$$q_s = \alpha \cdot Q_s \cdot \sin(\theta) \cdot A' \tag{4.8}$$

where θ is:

$$\theta = arccos[\cos(H_c) \cdot \cos(Z_c - Z_l)] \tag{4.9}$$

The electrical resistance of a bare, intertwined conductor changes with frequency, average current density and temperature. The calculated values of resistance for most of the standard aluminium conductors are given for frequencies of 60 Hz, from 25°C to 75°C. These calculated values include a skin effect dependent on frequency, for all types of intertwined conductors, but for others, except for the ACSR (Aluminium Conductor Steel Reinforced); they do not include the correction of the effects of the magnetic core dependent on current density, which is significant for the ACSR conductors that have odd numbers of intertwined aluminium conductor layers, IEEE [2].

Accordingly, electrical resistance is calculated only as a function of conductor temperature; however, the entered values for resistance can be a function of frequency and current density. For example, the value of conductor temperature at high temperature, T_{high}, and low temperature, T_{low}, can be taken from table values, see IEEE [2]. Conductor resistance at any other temperature, T_c, is calculated via linear interpolation according to the equation (4.10).

$$R(T_c) = \left[\frac{R(T_{high})-R(T_{low})}{T_{high}-T_{low}}\right] \cdot (T_c - T_{low}) + R(T_{low}) \tag{4.10}$$

Since, the specific resistance of most common metals used in intertwined conductors increases with temperature much faster than in a linear fashion, specific resistance calculated according to Equation 4.10 will be somewhat higher (it should be taken into account in the calculation) until the conductor temperature is between T_{low} and T_{high}. However, if the conductor temperature exceeds T_{high}, the calculated specific resistance will be somewhat lower. The conclusion is that the use of data for temperatures from 25°C to 75°C, the Alcan Cable Catalogue, [7], is appropriate for the rough calculation of thermal values for temperatures up to 175°C under constant and changing weather conditions, the approximate fault calculations could be made to the melting point of standard materials for conductors.

The heat capacity of the conductor is defined as a product of specific heat and mass per length unit. If the electrical conductor consists of more materials (e.g. ACSR line), then the heat capacities of the core and every external, surrounding intertwined waist are defined this way.

For the calculation of temperature, under transient state in time intervals from 5 to 30 minutes, the temperature of the conductor components remains approximately equal after the step increase of the current. The heat capacity of the conductor can be calculated as the sum of heat capacities of the components, according to the equation (4.11):

$$mC_p = \sum m_i C_{pi} \tag{4.11}$$

The heat capacity of the conductor is the sum of the products of the specific heat and mass per length unit of the component parts or components of the conductor. The mass per length unit of a conductor and the component parts or components of the conductor of all the usual aluminium and composite power lines is given in IEEE [2].

For example, with the 26/7 Drake ACSR conductor type, the weights of the steel core and external aluminium are 1.116 kg/m and 0.5119 kg/m, the total heat capacity at 25°C is as follows:

$$mC_p(Al) = 1.116\ kg/m \cdot 955J/kg°\mathrm{C} = 1066J/m°\mathrm{C} \tag{4.12}$$

$$mC_p(Steel) = 0.5519\ kg/m \cdot 476\ J/kg°\mathrm{C} = 262.7J/m°\mathrm{C} \tag{4.13}$$

Specific heat levels of the materials for electrical conductors is given in Table 1.

Table 1: *Specific heat of wire materials for conductors*

Material	J/(kg°C)
Aluminum	955
Copper	423
Steel	476
Aluminum clad steel	534

5 EQUATIONS FOR PROPERTIES OF AIR, ANGLES AND ENERGY FLUX OF THE SUN

Equations are given for viscosity (5.1), solar altitude (5.4), and azimuth (5.6). Tables of typical values are given for illustrative purposes.

Dynamic viscosity is determined as follows:

$$\mu_f = \frac{1.458 \cdot 10^{-6} \cdot (T_{film}+273)^{1.5}}{T_{film}+383.4} \tag{5.1}$$

Density of air can be determined from Table 2 or it can be calculated as follows:

$$\rho_f = \frac{1.293-1.525 \cdot 10^{-4} \cdot H_e+6.379 \cdot 10^{-9} \cdot H_e^2}{1+0.0036 \cdot T_{film}} \tag{5.2}$$

Thermal conductivity can also be determined from the table or by equation:

$$k_f = 2.424 \cdot 10^{-2} + 7.477 \cdot 10^{-5} \cdot T_{film} - 4.407 \cdot 10^{-9} \cdot T_{film}^2 \tag{5.3}$$

Table 2: *Viscosity, density and thermal conductivity of air*

Temperature T_{film}	Dynamic viscosity μ_f	Density of air – ρ_f (kg/m^3)				Thermal conductivity of air, k_f
°C	x10^6(Pas)	0 m	1000 m	2000 m	4000 m	W/(m°C)
0	17.2	1.293	1.147	1.014	0.785	0.0242
5	17.4	1.270	1.126	0.995	0.771	0.0246
10	17.6	1.247	1.106	0.978	0.757	0.0250
15	17.9	1.226	1.087	0.961	0.744	0.0254
20	18.1	1.205	1.068	0.944	0.731	0.0257
25	18.4	1.184	1.051	0.928	0.719	0.0261
30	18.6	1.165	1.033	0.913	0.707	0.0265
35	18.8	1.146	1.016	0.898	0.696	0.0269
40	19.1	1.127	1.000	0.884	0.685	0.0272
45	19.3	1.110	0.984	0.870	0.674	0.0276
50	19.5	1.093	0.969	0.856	0.663	0.0280
55	19.8	1.076	0.954	0.843	0.653	0.0283
60	20	1.060	0.940	0.831	0.643	0.0287
65	20.2	1.044	0.926	0.818	0.634	0.0291
70	20.4	1.029	0.912	0.806	0.625	0.0295
75	20.7	1.014	0.899	0.795	0.616	0.0298
80	20.9	1.000	0.887	0.783	0.607	0.0302
85	21.1	0.986	0.874	0.773	0.598	0.0306
90	21.3	0.972	0.862	0.762	0.590	0.0309
95	21.5	0.959	0.850	0.752	0.582	0.0313
100	21.7	0.946	0.839	0.741	0.574	0.0317

The altitude of the sun H_c in degrees (or radians) is given in Equation (5.4), in which independent variables are inverse trigonometric functions in degrees (or radians).

$$H_c = arcsin[\cos(Lat) \cdot \cos(\delta) \cdot \cos(\omega) + \sin(Lat) \cdot \sin(\delta)] \quad (5.4)$$

The hour angle, ω, is the number of hours from the noon multiplied by 15° (e.g. 11 hours am is -15°, 2 hours pm is +30°). Solar declination δ, is as follows:

$$\delta = 23{,}458 \cdot sin\left[\frac{284+N}{365} \cdot 360\right] \quad (5.5)$$

where the independent variable *sin* is given in degrees.

The equation is valid for all latitudes, both positive, and negative, i.e. the northern and southern hemispheres.

The solar azimuth Z_c (in degrees) is shown in Equation (5.6):

$$Z_c = C + \arctan(x) \tag{5.6}$$

where x is:

$$x = sin\left[\frac{\sin(\omega)}{\sin(Lat)\cdot\cos(\omega)-\cos(Lat)\cdot\tan(\delta)}\right] \tag{5.7}$$

The constant of the solar azimuth C (in degrees), is the function of hour angle ω, and the solar azimuth variable x, as shown in Table 3.

Table 3: *Constant of the solar azimuth C, as a function of hour angle, and the solar azimuth variable x*

Hour angle ω [°]	C if x>0°	C if x<0°
-180<ω<0	0	180
0<ω<180	180	360

Table 4: *Solar altitude H_c, and azimuth Z_c, at different latitudes for an annual peak, solar thermal input*

	Local sunny weather						
Latitude	10:00 h		noon		14:00 h		
(Degrees-North)	Hc	Zc	Hc	Zc	Hc	Zc	N
-80	32	33	33	180	32	327	350
-70	40	37	43	180	40	323	350
-60	48	43	53	180	48	317	350
-50	55	52	63	180	55	308	350
-40	60	66	73	180	60	294	350
-30	62	83	83	180	62	277	350
-20	62	96	90	180	62	264	20
-10	61	97	88	180	61	263	50
0	60	91	90	180	60	269	80
10	61	85	89	180	61	275	110
20	62	85	90	180	62	275	140
30	62	97	83	180	62	263	170
40	60	114	73	180	60	245	170
50	55	128	63	180	55	232	170
60	48	137	53	180	48	223	170
70	40	143	43	180	40	217	170
80	32	147	33	180	32	213	170

Table 5: *Total thermal flux, received by the surface at sea level*

Solar altitude degrees	Clear atmosphere	Industrial atmosphere
H_c (°)	Q_s (W/m^2)	Q_s (W/m^2)
5	234	136
10	433	240
15	583	328
20	693	422
25	770	502
30	829	571
35	877	619
40	913	662
45	941	694
50	969	727
60	1000	771
70	1020	809
80	1030	833
90	1040	849

6 COMPARATIVE ANALYSIS OF AMPACITY BY VALID CROATIAN STANDARDS AND IEEE STD 738-2006

Construction data for several typical types of ACSR conductors according to the ASTM (American Society for Testing and Materials) B232 standard are given in Table 6. Figure 2 displays compared ampacities of the table-listed ACSR types of conductors according to COG No. 24/97, [1], and IEEE, [2], for meteorological conditions on 7 May 2013 at 20:00.

Table 6: *Catalogue data for typical ACSR conductors for overhead power lines according to* Alcan Cable Catalogue [6]

Code name	Area and ratio of the cross section		Resistance		
	Nominal cross section [mm^2]	Section ratio Al/Cu	DC resistance [Ω/km] at 20°C	AC resistance at 60 Hz [Ω/km]	
				at 25°C	at 75°C
Waxving	135.18	18/1	0.2113	0.2150	0.2580
Chickadee	201.41	18/1	0.1417	0.1450	0.1730
Hawk	241.69	26/7	0.1171	0.1200	0.1440
Swift	322.26	36/1	0.0876	0.0920	0.1130
Starling	362.54	26/7	0.0781	0.0800	0.0958
Drake	402.82	26/7	0.0702	0.0728	0.0793

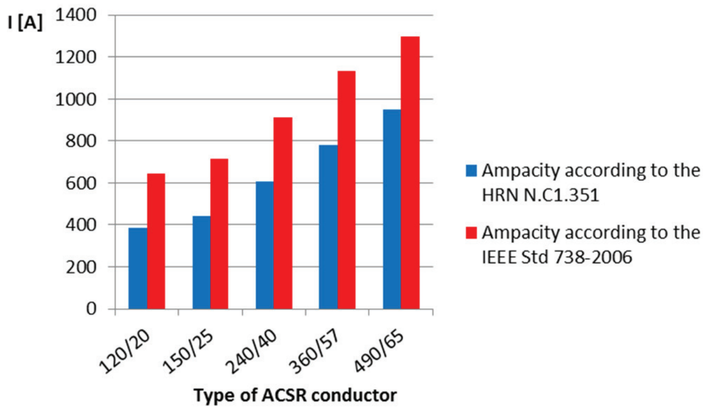

Figure 2: *Comparison of ampacities by applied standard on 7.5.2013 at 20:00 h*

Figure 2 displays the compared, calculated ampacities of the applied standard, COG No. 24/97, [1], (blue bars) and IEEE, [2] (red bars). The calculation is done for the relation between Zagreb and Osijek on 7 May 2013 at 20:00 when the ambient temperature was between 15°C and 20°C, wind speed around 2 m/s, the result of which was 30% higher ampacity of the ACSR line.

Table 7 gives the catalogue list of ACSR conductors' typical construction according to the HRN N.C1.351 standard with allowed continuous current, which is the result of a calculation with a temperature of 40°C and a wind speed of 0.6 m/s.

Table 7: *ACSR conductors, typical construction according to the* HRN N.C1.351, Technical Manual Končar, [7]

Nominal cross section [mm²]	Section ratio Al/Steel	Longitudinal resistance at 20°C [Ω/km]	Resistance at 80°C [Ω/km]	Allowed permanent current [A]
120/20	26/7	0.23740	0.2948	385
150/25	26/7	0.19390	0.2410	442
240/40	26/7	0.11880	0.1475	605
360/57	26/19	0.08014	0.0995	780
490/65	30/19	0.05924	0.0733	951

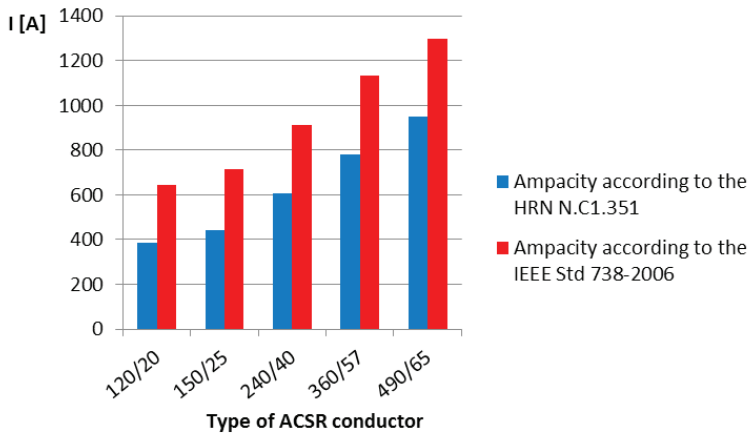

Figure 3: *Comparison of ampacities by applied standard on 7.5.2013 at 20 h*

Figure 3 shows the compared results of allowed ampacity depending on the applied standard, for typical constructions of ACSR conductors according to the HRN N.C1.351 standard. It can be seen that the ampacity in the case of IEEE Std 738 is 25% to 40% higher than the results according to the COG No. 24/97, [1].

In conclusion, it can be said that ACSR conductors are loaded under the limit most of the time. The ampacity that is considered as a standard is valid for a very short time period of the year. The most unfavourable day in 2012 was 6 August, on which the temperature reached 40°C throughout Croatia, but only between 10:00 and 17:00. This fact is significant because of the possibility for a particular power line to become overloaded for a definite time interval beyond the limits set by legislation, in order to meet the requirements of demanding market participants.

7 CALCULATION SENSITIVITY ON INPUT PARAMETERS

According to IEEE Std 738-2006, described in previous chapters, calculation of ampacity considering input parameters is (beside ambient temperature and the time of the day) is most sensitive when the speed and direction of the wind are taken into account. The accuracy of the method according to the applied standard has been the subject of discussion, but there were determined minimum deviations in regard to the actual situation, Strobach, Straumann, Franck, [4], and Lindberg, [5]. For example, the ACSR conductor, type 490/65 on the relation between Zagreb and Osijek is taken. In this account, the initial data of conductor characteristics, the location of the power line and the weather conditions of the meteorological stations are taken for 12 May 2013 at 13:00. The most unfavourable factor in the calculation is the analysis of wind motion. Fluctuations in air motions are continuous and constantly changing. Figure 4 shows the impact of the incident angle between the wind flow and power line direction on the final result of the maximum allowed current. An error that can be entered in the calculation is not significant if it is an angle between 70° and 90°. However, for angles up to 30°, errors can amount to 20% of the total allowed current value. The differences are more pronounced as the wind speed increases.

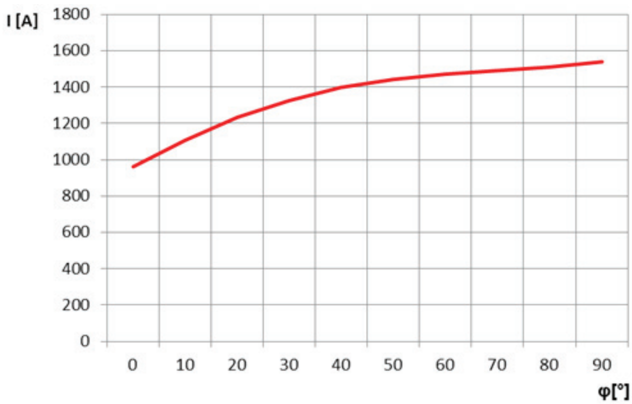

Figure 4*: The interdependence of the angle between the direction of the wind and the power line with ampacity*

It is practically impossible on the longer sections of the power line to define for every moment the angle between the direction of the wind in relation to the direction of the power line, except in the case of the network of meteorological stations along the route of the power line. In that case, the calculation must take into account the most unfavourable data, especially for long relations like the one between Zagreb and Osijek. While the weather conditions on individual sections can be ideal, there is only one section needed where conditions are such that the heat gain by insolation is maximum, and the wind flow is not present.

8 BORDERLINE CASE

The requirement that the maximum conductor temperature not exceed +80°C under constant ambient temperature of +40°C is set so that even in the summer the power line is not found to be at risk of excessive thermal stress causing deformation of material and illicit sag. As a reference example of such a case, a calculation on 6 August 2012 (according to the state hydro meteorological office the hottest day since systematic measurements began) can serve. Figure 5 shows compared ampacities according to the catalogue data from Table 8 for ACSR conductor type 490/65 and those according to calculation in the IEEE Std 738-2006. For the weather conditions that caused different results, especially significant is the impact of the wind and the time of the day. At the time of the highest temperature of 40.5°C at 17:00, ampacity was above catalogue value of 951 A, due to the time of the day when the solar radiation is not as intense as it is during the middle of the day. Moreover, regarding the data for 13:00, when the ampacity is above the catalogue value although it is at a time of intense solar radiation, such a result is a consequence of the wind speed and direction during that hour. Figure 5 gives data for the thermally most unfavourable time of the day, i.e. between 10:00 and 17:00. From Figure 5, it is also visible that during the engagement of the particular power line it is not safe to perform transmission, taking into consideration data acquired for each hour, because such result is subjected to frequent changes due to the changes of the input parameters. However, the operation regime can be scheduled on the principle of summer and winter periods, as well as the ampacity zones depending on the time of the year.

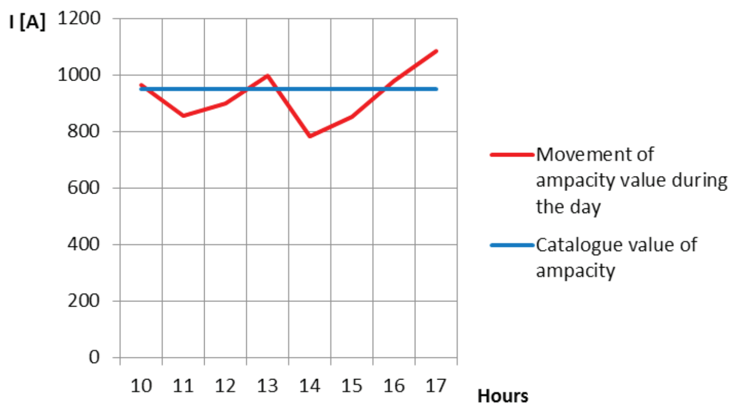

Figure 5: *Value of ampacity during 6.8.2012.*

9 CONCLUSION

The purpose and the objective of the IEEE Std 738-2006 method is to show the impact on the method for the calculation of the relation between the current and the temperature in bare, non-insulated, overhead power lines. The temperature on the surface of the conductor is a function of current weather conditions, surface conditions of the conductor, the diameter of the conductor and the properties of conductor materials. This paper shows the calculation method for the current and the temperature relation of bare, overhead power lines under given weather conditions. In addition to the mathematical part, the sources of values that are needed to use when calculating are indicated. The method does not generate the list of actual relations between the current and allowed ampacity of a large number of conductors, but primarily provides a standard method for performing such calculations.

For the purpose of the method, it is assumed that the current is unchangeable and continuous for the entire time, or that it is gradually changing from the initial to the final value. It is also assumed that the weather conditions are continuous during the time interval used for the calculation.

An overview of the ampacity calculation for typical weather conditions according to the IEEE Std. 738-2006 and according to the valid legal regulations is given in Chapter 6. The compared figures give the sense of a set limit for ampacity that cannot be reached most of the year. The borderline case is when the values of ampacities approach each other are the hottest days, i.e. only in the limited period of time during the middle of the day in the hottest summer months.

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Nomenclature

A' [m²/m]	Projected area of conductor per unit length
C [degrees]	Solar azimuth constant
C_{pi} [J/kg oC]	Specific heat of i^{th} conductor material
D [mm]	Conductor diametar
H_c [degrees]	Altitude of sun
H_e [m]	Elevation of conductor above sea level
I [A]	Conductor current
I_i [A]	Initial current before step change

I_f [A]	Final current after step change
K_{angle}	Wind direction factor
K_{solar}	Solar altitude correction factor
k_f [W/m°C]	Thermal conductivity of air at temperatureT_{am}
Lat [degrees]	Degrees of latitude
mC_p [J/m°C]	Total heat capacity of conductor
m_i [kg/m]	Mass per unit length of i^{th} conductor material
N	Day of the year (21. january = 21, 12. february = 43, etc.)
$q_{cn,} q_{c1}, q_{c2}$ [W/m]	Convected heat loss rate per unit length
q_r [W/m]	Radiated heat loss rate per unit length
q_s [W/m]	Heat gain rate from sun
Q_s [W/m²]	Total solar and sky radiated heat flux rate
$R(T_c)$ [Ω/m]	AC resistance of conductor at temperature T_c
T_a [°C]	Ambient air temperature
T_c [°C]	Conductor temperature
T_f [°C]	Conductor temperature many time constants after step increase
T_i [°C]	Conductor temperature before the step increase
T_{am} [°C]	$(T_c + T_a)/2$
T_{low} [°C]	Minimum conductor temperature for which ac resistance is specified
T_{high} [°C]	Maximum conductor temperature for which ac resistance is specified
V_w [m/s]	Speed of air stream at conductor
Z_c [degrees]	Azimuth of sun
Z_l [degrees]	Azimuth of power line
Δt [s]	Time step used in transient calculation
ΔT_C [°C]	Conductor temperature increment corresponding to time step
α	Solar absorptivity (0,23 do 0,91)
Δ [degrees]	Solar declination (od 0 do 90)
ε	Emissivity (0,23 do 0,91)
φ [degrees]	Angle between wind and axis of conductor
β [degrees]	Angle between wind and perpendicular to conductor axis
ρ_f [kg/m³]	Density of air
Θ [degrees]	Effective angle of incidence of the sun's rays
μ_f [Pas]	Dynamic viscosity of air
ω [degrees]	Hours from local sun noon times 15
χ	Solar azimuth variable

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SMALL HYDROPOWER PLANTS IN SLOVENIA

MALE HIDROELEKTRARNE V SLOVENIJI

Primož Mavsar[ℜ]

Keywords: small hydropower plants, hydrological potential, renewable sources

Abstract

In this article, an overview of the small hydropower (SHP) sector in Slovenia and the EU is given. Data were collected from publically accessible statistics (SURS and EUROSTAT) and public documents available on the internet. The gross production of electric energy from small hydropower plants, its share in production from renewable sources, available hydrological potential, trends in SHP sector and strategic development for the future are all considered. EU experts optimistically predict increasing SHP capacities while the statistical data for the previous decade show the opposite.

Povzetek

V članku je podan pregled stanja v sektorju malih hidroelektrarn v Sloveniji in EU. Podatke smo pridobili iz javno dostopnih statistik (SURS and EUROSTAT) in iz javno dostopnih dokumentov objavljenih na spletu. Obravnavamo bruto proizvodnjo električne energije malih hidroelektrarn, njihov delež v proizvodnji iz obnovljivih virov, razpoložljiv hidrološki potencial, trende v sektorju malih hidroelektrarn in njihov strateški razvoj v prihodnosti. Napovedi evropskih strokovnjakov optimistično napovedujejo rast kapacitet malih hidroelektrarn, vendar statistični podatki kažejo ravno nasprotno sliko.

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1 INTRODUCTION

Throughout the world and also in Slovenia, electric energy consumption is rising every year. To ensure a quality supply for the future and to decrease Slovenia's dependency on energy imports, production capabilities must be increased, or the trend of rising consumption must be reversed. The latter option requires significant changes in behaviour, thinking and lifestyle. In accordance with sustainable development, reduced consumption and increased production must be pursued, accompanied by an increased share of renewable sources of energy (RSE). Hydropower has a significant role in reaching the 2020 renewable energy targets as well as the greenhouse gas reduction targets. The target for Slovenia is to attain a 25% share of renewable sources in final energy consumption and a minimum share of renewable electricity consumption of 34%, [1].

With regard to water resources, Slovenia is one of the richest EU countries; with significant hydrological potential to exploit for the generation of electricity. This potential can be harnessed without significant impact on the environment, with minimal pollution and at relatively low cost with the use of technology of small hydropower plants (SHP), which is very well known and efficient.

The definition of SHP differs from country to country. Slovenia has defined it as hydropower plants whose maximum installed capacity does not exceed 10 MW. This definition is also approved by the European Small Hydropower Association (ESHA).

An SHP is not simply a reduced version of a large hydropower plant, but requires special equipment that ensures high efficiency, maintaining simplicity for non-experts, environmental measures and maximum reliability [2].

SHPs can be divided into two groups according to their ecological impact, [3]. The first group consists of run-of-river power plants, which can be subdivided to: diversion hydroelectric plants (plants involving a partial diversion of water of the water of the river) and through-flow power plants (plants with no diversion but run-through regimes). The second group is infrastructure-related power plants, also called multipurpose plants, which exploit water that has already been used for other purposes. They produce only small amounts of electricity and are usually integrated into the network of the drinking water supply, wastewater disposal infrastructure or irrigation infrastructure. They can also exploit the excess of water of larger plants and can aid in the creation of flows to aid fish migration.

2 OVERVIEW OF THE CURRENT SITUATION

This research is mainly based on publically accessible statistical data (SURS and EUROSTAT) and public documents available on the internet.

Electricity consumption in Slovenia rose continually from the year 2000 to 2012 (Figure 1). The only exception was 2009 when there was a significant drop of consumption (to the level of 2001) due to beginning of the economic crisis. Since then, consumption has again risen.

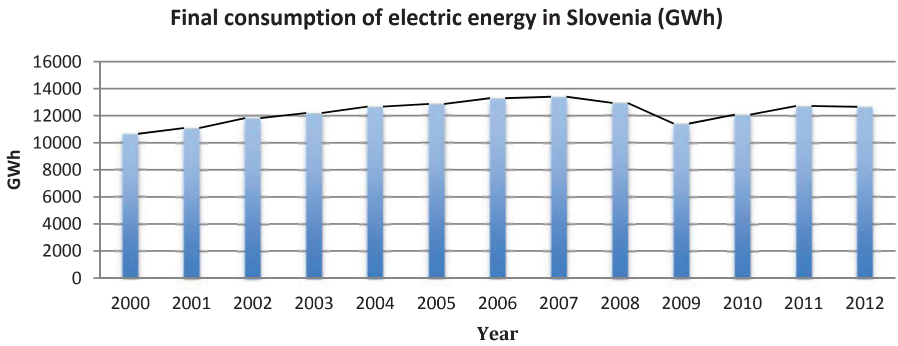


Figure 1: *Electric energy consumption from year 2000 to 2012 [5]*

In 2012, electricity was mainly produced from nuclear fuel (Figure 2). Renewable sources had a 29% share if hydropower and other sources (photovoltaic, biomass and biogas) are taken into account.

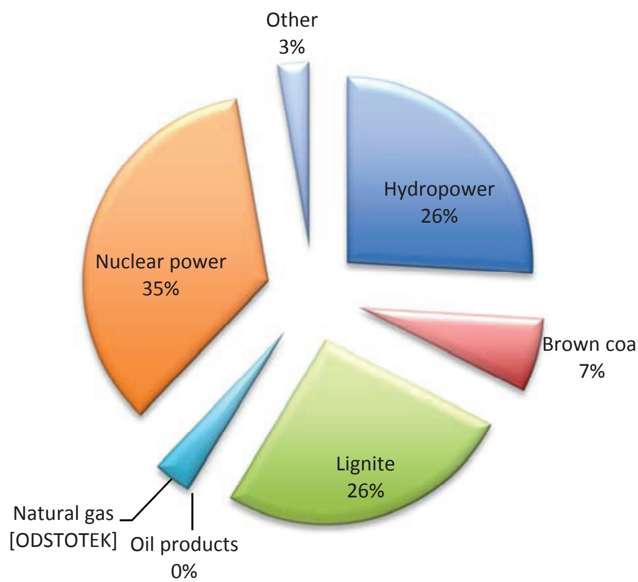


Figure 2: *Electric energy production by source in 2012, [5]*

The largest share (80%) of electricity production from renewable sources in 2012 was held by large hydropower plants. The second largest share was held by SHP at 7% (Figure 3). The SHP share and gross production was even bigger from 2000 to 2012. (Figure 4).

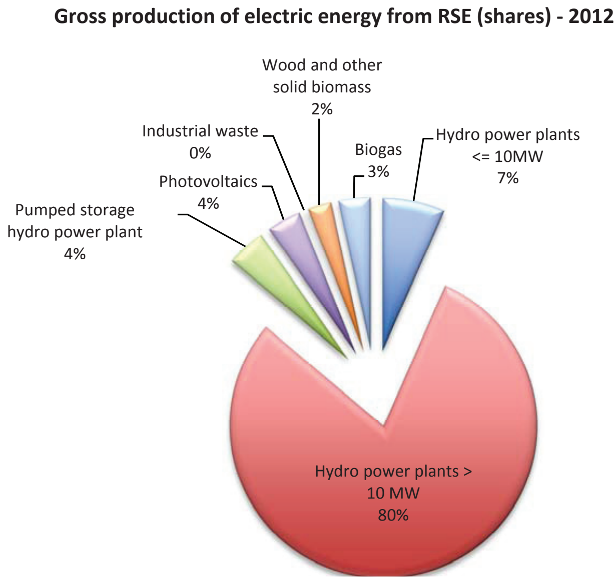


Figure 3: *Gross production of electric energy from RSE [5]*

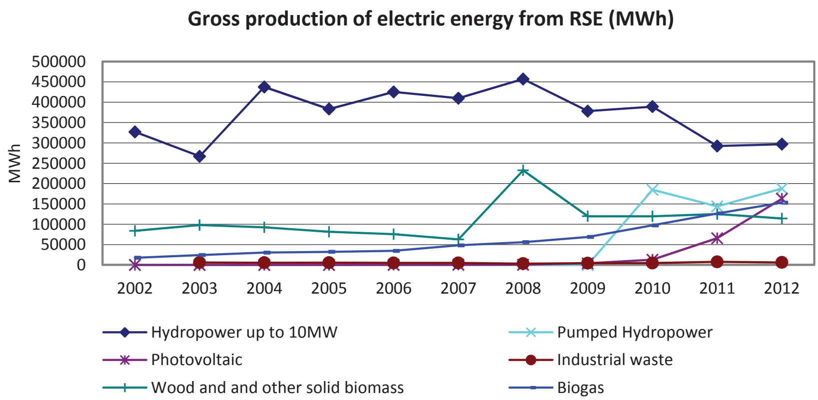


Figure 4: *Gross production of electric energy from RSE over past 10 years – large Hydropower plants not included, [5]*

The hydro-electric gross potential of Slovenian rivers is estimated to 19440 GWh/year, of which 9145 GWh/year is technically feasible and between 7000 and 8500 GWh/year is economically feasible, [4].

In 2013, 4080 GWh of electric energy was produced, which represents 45% of the entire technically feasible potential; 297 GWh of that production was produced by SHP, which is 7% of all electricity produced by hydropower, [5]. The hydrological potential suitable for SHP is estimated at 1114 GWh/year (not including the Kolpa and Mura rivers). Currently, approximately 25% of that potential is harnessed, [4], which leaves 835GWh/year to exploit.

In Slovenia, 407 SHPs with an average installed capacity of 234 kW are currently active, [6]. These are the SHPs that have concessions for water exploitation; the authority for granting such concessions is the Slovenian Environment Agency.

SHP are situated mostly in the Alpine region, in the north and north-west of the country (Figure 5). These regions have the most of SHP exploitable potential, because Alpine rivers are water abundant with high water heads.

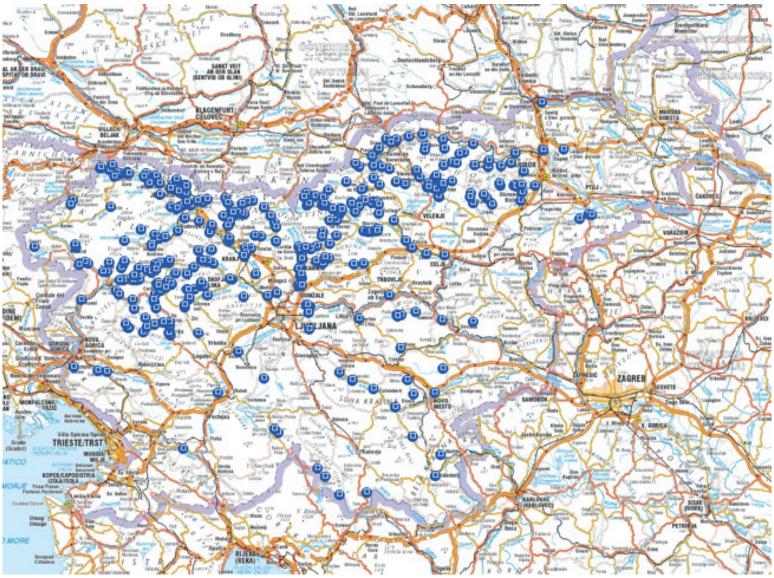
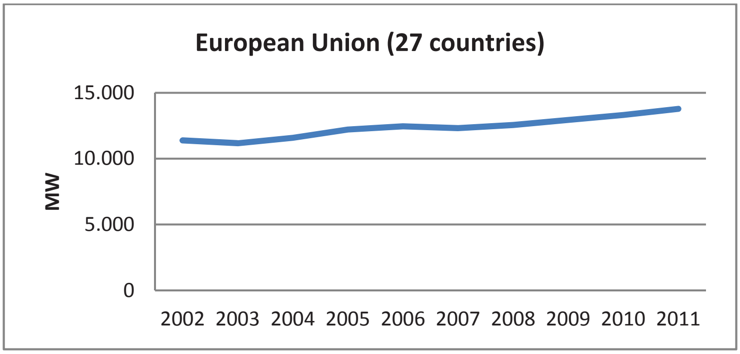


Figure 5: *SHP on the map (source: http://www.geopedia.si/)*

3 SHP TRENDS IN SLOVENIA AND THE EU

Most of the SHPs in Slovenia were built before its declaration of independence in 1990. The real boom of new SHP was in the 1980s; this was caused by energy legislation that allowed building SHPs in non-electric power industrial facilities, [7]. More than 80% of operating SHPs originate from that time. Since then, new legislation has almost halted the building new SHPs. The situation in the rest of EU is similar, [8].

If the installed power of SHP from 2002 to 2011 in the EU is considered, it rose approximately 2% per year. Installed SHP power in Slovenia has also risen, but a drop of 8% was recorded 2003 and 2004. After 2006, it continued to rise again at average of 2% per year (Figure 6). Although the installed power of SHP is rising, the gross production of electricity has been dropping since 2008 (Figure 4).



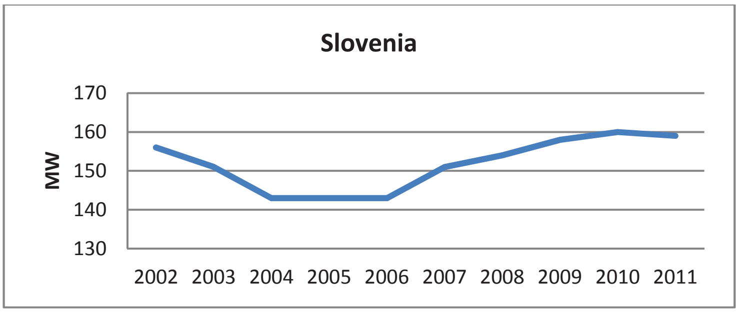
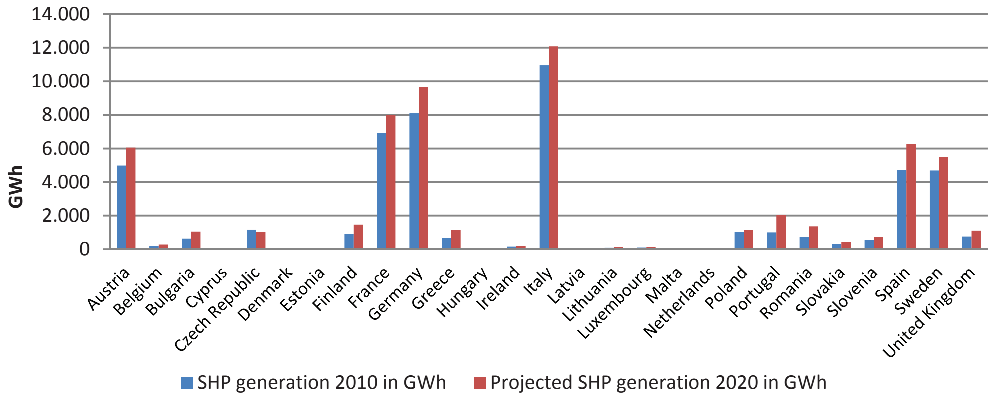


Figure 6: *Installed capacity of SHP in EU-27 and Slovenia [9]*

In 2010, approximately 21,800 active SHPs in the EU-27 generated 49,000 GWh of electricity and accounted to over 13,000 MW of installed capacity, which is enough to supply over 13 million households. This contributes to an annual reduction of CO_2 of 29 million tonnes, [10].

The ESHA (European Small Hydropower Association) made projections of generation of electricity by SHP from 2010 to 2020. They predict a 23% increase of total production in the EU-27 (Figure 7). The largest increase of production is predicted for Netherlands and Portugal (over 100%). Only for the Czech Republic is a decrease predicted (10%). The forecast for Slovenia is a 35% increase.



Member State	SHP electricity capacity in MW	SHP generation in GWh	Projected SHP generation 2020 in GWh
Austria	1.109	4.983	6.050
Belgium	64	178	285
Bulgaria	285	630	1.050
Cyprus	-	-	2
Czech Republic	297	1.159	1.040
Denmark	9	21	31
Estonia	8	30	33
Finland	302	900	1.460
France	2.110	6.920	8.000
Germany	1.723	8.098	9.650
Greece	183	657	1.150
Hungary	14	67	80
Ireland	45	160	200
Italy	2.735	10.958	12.077
Latvia	26	69	85
Lithuania	29	93	120
Luxembourg	34	100	137
Malta	-	-	-
Netherlands	2	8	18
Poland	275	1.035	1.136
Portugal	360	997	2.032
Romania	387	719	1.360
Slovakia	80	303	443
Slovenia	117	535	720
Spain	1.926	4.719	6.280
Sweden	1.134	4.694	5.500
United Kingdom	230	750	1.100
TOTAL	**13.485**	**48.783**	**60.039**

Figure 7 and 8: *EU-27 SHP Generation 2010 and 2020 Forecasts (source: http://dev02.semaforce.eu/index.php?id=263)*

4 STRATEGIC DEVELOPMENT OF SHP

Because most of the SHPs are situated in the Alpine region, which is environmentally highly fragile, and because sustainable development must be planned, SHP development guidelines and recommendations of Alpine Convention should be adopted, [2]; these were approved by the 11th Alpine Conference held in Brdo pri Kranju, Slovenia in 2011. These guidelines and recommendations are oriented towards the usage of renewable resources and decentralized plants.

The SHP sector continues to face significant obstacles, especially with increasing environmental demands and administrative barriers. Therefore, far-reaching increases in the development of new SHPs cannot be expected. The gross production of electric energy from SHP has even been dropping since 2008 (Figure 4).

For the future development of the SHP sector, two possible scenarios are predicted, [11]. The first scenario is the development of SHP if the conditions will remain as they are currently, while the second scenario predicts that the condition will improve.

The first scenario predicts that the development of new SHPs will expand more slowly because the most suitable places already have been used. Furthermore, the refurbishment of old abandoned SHPs will be questionable because of new stricter environmental regulations. For the EU-27, this scenario estimates that one-third of the potential can be developed with existing conditions by 2020.

The second scenario estimates the growth will be the same until the year 2020, which means that two thirds of the EU-27 potential can be developed, i.e. a total SHP capacity of 20 GW. That is 3.3GW more than estimates of the first scenario or 13,000 GWh per year. Because Slovenia is a member state of the EU-27, two similar scenarios can be expected.

Slovenia's plan for increasing its share of renewable sources is to provide a wide range of technology to harness them. The priority for electric production is to promote the sectors with significant economic potential, i.e. hydropower, biomass and biogas, [12]. When the trend in decentralized power plants and the fact that SHPs demonstrate the best performance with regard to emissions measured on a lifecycle basis are taken into account, the SHP sector is one that should be more present in national and regional financial and planning incentives.

If the target of a 25% share of renewable sources is to be attained, all available potentials must be used. Therefore, it is necessary that government and policy makers consider the SHP sector to be an equally important component of the renewable energy mix and as a technology that supports water management policies. More consensus and cooperation between the energy and environmental policies and actors is also needed, [13].

The development of SHPs is also a major challenge for Slovenia's SHP industry, which has a significant role in the EU and further abroad. The SHP industry must obtain a competitive role and has to invest in developing new technologies and knowledge in automation, frequency conversion, permanent magneto-generators, efficient, low head turbines, fish-friendly turbines and new materials, [11]. Throughout the world, there is a considerable amount of un-used hydrological potential, and this represents an excellent opportunity.

Refurbishing old existing SHPs or renovating old mills into SHPs are more appropriate courses of action than building new plants, because there is a smaller impact on the environment as well as added value in the sense of preserving a technical legacy and promoting tourism. All of this contributes to the development of rural regions and job creation.

5 CONCLUSION

In this article, a quick overview of the situation in the small hydropower sector in Slovenia and the EU has been made. Slovenia has significant hydrological potential, of which 25% is currently harnessed by SHPs. The production share of electric energy from SHP in Slovenia is currently 7% but is decreasing due to the increased usage of other renewable sources, as well as EU and state policies. The European Small Hydropower Association has predicted an increase of installed SHP capacity by one third by 2020 for Slovenia, but the current trends indicate the opposite.

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GLOBAL TRENDS AND THE THERMAL ENERGY CAPACITIES GREATER THAN 10 MW IN SLOVENIA

SVETOVNI TRENDI IN STANJE TERMOENERGETIKE NAD 10 MW V SLOVENIJI

Dušan Strušnik[ℜ]

Keywords: thermal energy, trends, primary sources, coal, thermo-power station, Kyoto protocol, ecology, electricity, fire

Abstract

Thermal energy is the most significant form of energy production and is of key importance for satisfying global energy needs. When combusting primary fuel in thermal power stations, environmentally dangerous greenhouse gases are released as a consequence of obtaining electrical and thermal power. Strict environmental energy legislation requires thorough changes to thermal power stations. This paper analyses global, European and Slovene trends of the consumption of primary sources (coal, natural gas, etc.) and the adjustment of thermal power stations to energy needs and environmental legislation. Two anticipated scenarios (Basic and Blue) of trend flows are discussed, and guidelines are given. Thermal energy facilities, development guidelines and the energy dependences of Slovenia will be presented.

Povzetek

Termoenergetika je najpomembnejša panoga pridobivanja energenta in je ključnega pomena pri zadoščanju globalnih energetskih potreb. Z zgorevanjem primarnih goriv se v termoelektrarnah sproščajo okolju nevarni toplogredni plini, pri čemer pridobivamo električno in toplotno energijo.

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Zaradi stroge okoljsko-energetske zakonodaje, se bo moral termični način pridobivanja energentov temeljito spremeniti. Analizirali bomo svetovne, evropske in slovenske trende porabe primarnih virov (premog, zemeljski plin…) in prilagoditev energentov na energetske potrebe in okoljsko zakonodajo. Obravnavali bomo predvidena scenarija (osnovni in modri) gibanja trendov in podali smernice. Predstavili bomo termoenergetske objekte, razvojne smernice in energetsko odvisnost Republike Slovenije.

1 GLOBAL TRENDS OF THERMAL ENERGY

Thermal energy science is concerned with the usage of thermal energy and its transformation into other forms of energy. The oldest heat sources are the sun and fire. Fire has been a vital source of energy since prehistory and is one of the oldest human inventions, [1], used directly for heating, cooking and lighting. Human mental development, which is based on division and separation (mine-yours, left-right, etc.), enables discovering deeper stages and seeks the essence of an object in its details. This led from the discovery of fire to the ability to transform thermal energy into mechanical force and other forms of energy.

The need for energy is ever increasing throughout the world as the global population continues to grow numerically and economically. The growing need for energy is the greatest in Asia, especially in the growing economies of China and India. The largest parts of the world´s energies are spent by the USA and China, [2]. Despite an encouraging level of developing low-carbon energy production, without the usage of fossil fuels, the world's energy needs cannot be satisfied.

Estimations of world's supply of primary energy sources shows that this supply is very limited and (except for coal) will not satisfy the normal supply of world's needs to the end of the 21st century, [3]. With regard to exploiting primary sources, coal has the leading position, with which natural gas partly competes. The developing technology of obtaining energy from gas is expanding, as are techniques for the extraction of gas from solid primary sources (coal, wood, slate, etc.). With the gasification of solid fuel, transport becomes more economical, and pollution is reduced. With the continued development of gas technology bringing about greater efficiency, gas will take the leading role.

1.1 Usage trends of coal, gas and production energy

From a global perspective, most energy is produced by burning coal ore and gas. Consumption has changed according to the growth of the population, technological progress, economic status, supplies, etc. This trend was linearly increasing until 1995, stabilized by 2008 and recently has even decreased. The consumption of coal did not stabilize because of decreased global energy needs but because of increased production of energy from other sources.

From Fig. 1, it is evident that since 2006 there has been a production increase of gas, oil, biomass and a lower consumption of coal.

The consumption trends of energy sources indicate that we are aware of ecological issues and that cleaner technologies are used (Kyoto protocol).

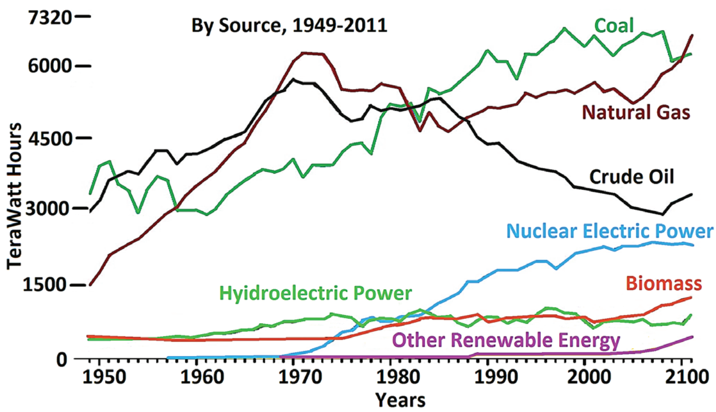

Figure 1: *Global trends of fuel consumption, EIA [4]*

The Kyoto protocol is an international treaty that attempts to reduce the emission of carbon dioxide and five other greenhouse gases. This protocol has been valid since February 2005. By 2009, the treaty had been ratified by 183 countries and the European Union. At the time of signing the protocol, 37 developed countries and 15 member countries of the European Union agreed to the obligations of reaching the Kyoto aims, [5]. In Article 17 of the Kyoto protocol, the trading of emission quotas is defined. Consequently, in the case of emissions of greenhouse gases that are higher than allowed, the signatory countries have to buy emission quotas on the market. These greenhouse gas emission quotas, which are granted to the member states, will be reduced in the course of time, which means that the countries will have to buy quotas on the market or invest into new technologies. As a result of this treaty, we can expect further decreases of coal technology, as the technology for natural gas will be economically more favourable. There has been a decrease of emissions of carbon dioxide produced by burning coal and an emission increase of carbon dioxide produced by burning gas since 2006 (Fig. 2). This trend should also continue in the future.

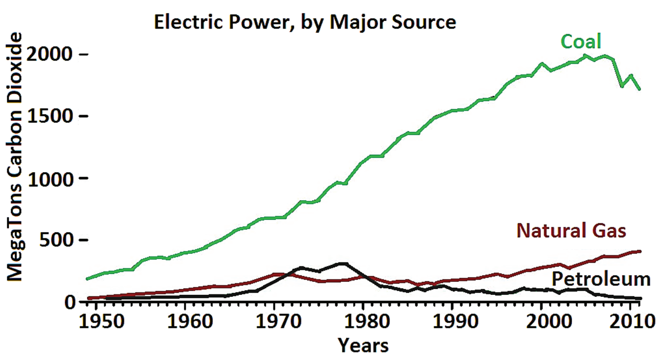

Figure 2: *Emission of gas CO_2, EIA [4]*

A negative trend of coal usage is evident in thermoelectric plants, as modern gas technologies for producing electricity are becoming increasingly effective, efficient and profitable. If the progressively demanding ecological restrictions are also considered, gas has massive potential. Global energy usage trends also indicate a decrease of coal technology and an increase of gas technology (Fig. 3).

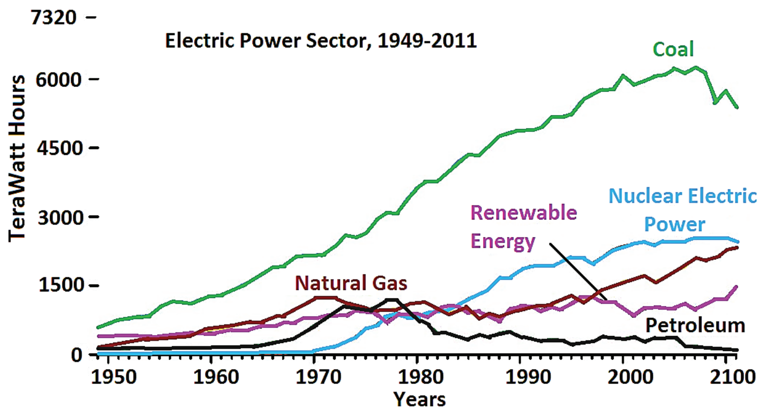

Figure 3: *Production of electricity, EIA [4]*

From a global perspective, in 2002 50% of electricity was produced by burning coal and 18% by burning gas. By 2012, the production of electricity obtained from coal had been reduced by 37%; the production of electricity obtained from gas had increased by 34%. It is notable that the increased gas consumption is matched with the beginning of gas production from unconventional sources (e.g. slate) in 2009.

The trend of energy consumption in Europe is decreasing, because of the financial crisis; both trends (the energy trend and financial crisis) are simultaneous. There is a decrease in economic activity, including industry, production, and purchasing power; consequently, the need for energy is also decreasing. Nevertheless, increased consumption of gas can be observed, because of the lower usage of coal (Fig. 4). European consumption trends are compatible with global trends and are based on cleaner technology.

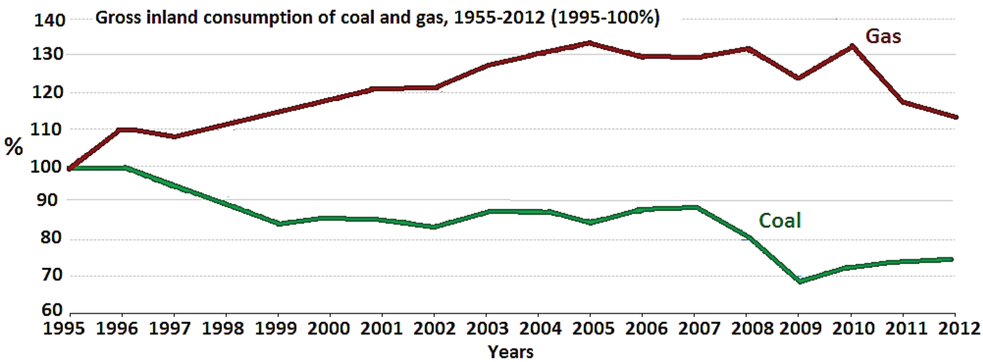

Figure 4: *Usage of coal and gas [6]*

In March 2007, The European Commission for a Lower Carbon Society accepted additional commitments [7].

These commitments are:

- Emissions decrease of greenhouse gases by 20% and, according to special conditions, even by 30%, in the period from 1990 to 2020,
- increase of renewable energy sources by 20%, and
- improvement of energy efficiency by 20%.

1.2 Long-term trends

Long-term global trends indicate a steady increase of energy needs, which will be provided by increased usage of already known fuels. Of key importance to fuel usage are economic guidelines. The International Energy Agency, [8], has presented two anticipated scenarios: the Basic and the Blue courses of events. They represent a basis for further economic development strategy and are based on implementation of low carbon technologies to 2050, [9].

According to the Basic Scenario, any new energy or environmental policy will not be accepted. The average anticipated global economic growth is per 3.1% yearly.

The Blue Scenario is based on a low carbon society. It anticipates that by the year 2050 the global emissions of carbon dioxide will decrease to a level of 50% of the current amount and that global temperatures will not rise by more than 2°C or 3°C. This goal can only be achieved when there will also be a decrease of the emission of other greenhouse gases, in addition to the measures for reductions of carbon dioxide, [9]. To achieve the aims defined in the Blue Scenario, significant reductions in emissions in all sectors will have to be achieved by 2050: electricity, industrial and building sectors. In this case, the difference between the produced and consumed energy will have to be substituted by alternative sources.

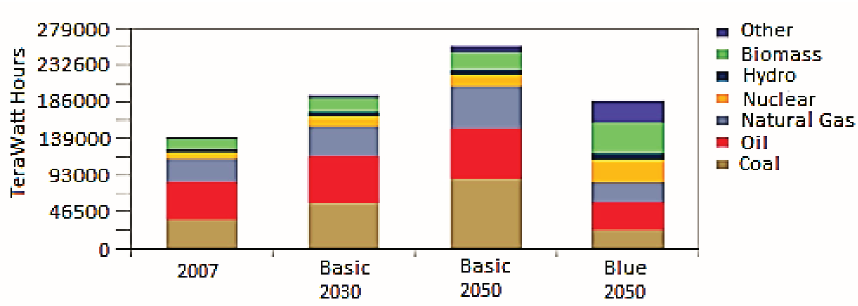

Figure 5: *Primary energy needs according to the energy source and guidelines scenario [9]*

The IEA's prediction of a consumption trend of coal and gas is shown in Fig. 6.

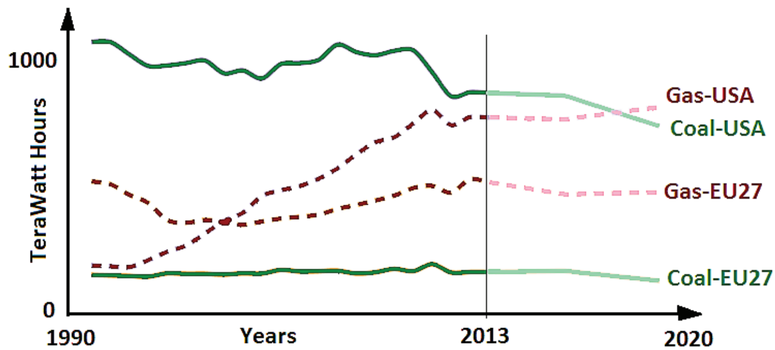

Figure 6: *Consumption trends of coal and gas, IEA [8]*

2 STATUS OF THERMAL ENERGY IN SLOVENIA

Slovene and European trends have no fundamental differences, because they are based on the same environmental and energy directives. Slovenia consumes solid fuel in thermoelectric plants for the production of electricity and thermal energy. Because the domestic production of solid fuel does not satisfy current needs, some fuel is imported (Fig. 7). Over time, the amount of imported solid fuel has been quite consistent, and it will gradually increase in the future, because of a decrease of domestic production.

The largest deficiencies in the usage of coal are its greenhouse gases. Therefore, the usage of domestic coal is in the future will be limited to lignite from the Velenje coal mine, for the production of electricity. The Kyoto protocol goal is the long-term reduction of all coal usage. The gradual closing of the Velenje coal mine is predicted around the year 2054. The closing of the Trbovlje-Hrastnik mine is predicted to occur in 2015, in accordance with the law on the developmental restructuring of the region. With the gradual decrease of the amount of coal usage, coal remains an element of domestic energy supply because of its strategic reliability and the diversification of energy sources, [10]. By 2020, Slovenia will have gradually stopped importing coal for the production of electricity.

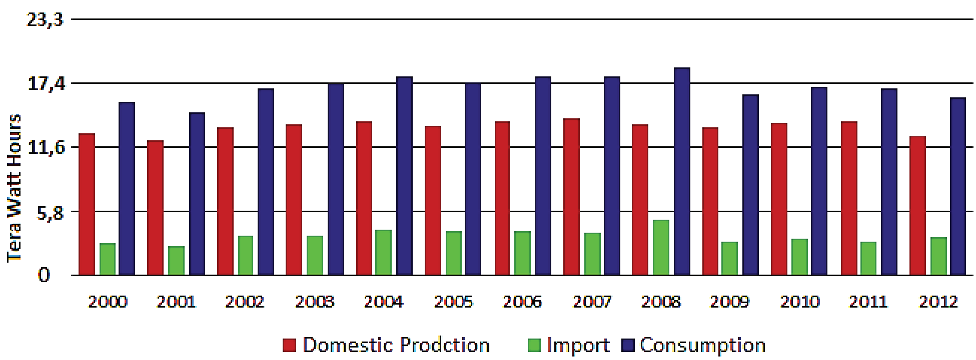

Figure 7: *Consumption trends of firm fuels in Slovenia [11]*

Slovenia imports almost all its natural gas. The energy needs for natural gas are increasing, and its price is formed on the market. The global trend is based on increased consumption of gas; higher gas prices can thus be expected. As a consequence, there will be increased energy dependence and more expensive energy for the consumer.

For the supply of natural gas, the gradual convergence with the neighbouring markets will be of key importance. The competitiveness of the natural gas market will improve. Gas consumption will depend on electricity production, especially in high-efficiency joint production in local supply and industry.

The assurance of energy service from remote heating systems will have priority over the extension of gas networks to new regions, [10].

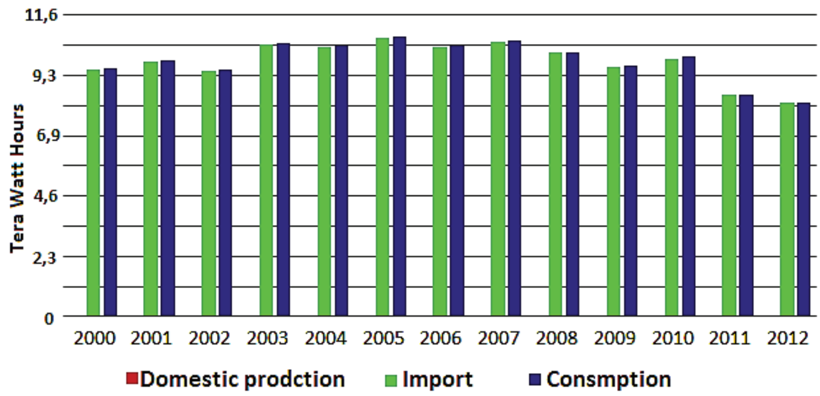

Figure 8: *Trend of natural gas in Slovenia [11]*

Fig. 9 shows the usage of energy sources, which is fairly stable. On average, Slovenia imports 51% of its energy resources (energy dependence), and this will increase in time. Most energy is produced by burning solid fuels.

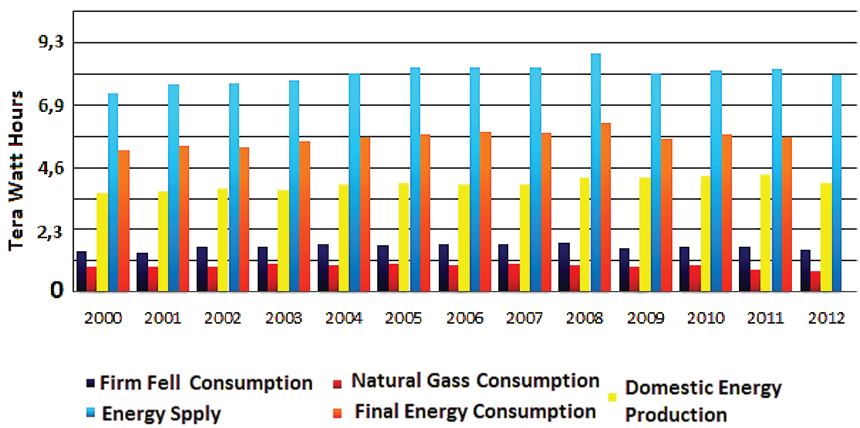

Figure 9: *Energy indicators in Slovenia [11]*

2.1 Thermal energy facilities with more than 10 MW capacity in Slovenia

Thermoelectric plant Šoštanj (TEŠ)

With 779 MW of power, TEŠ produces one third of the energy in the country. The annual production of electricity ranges from 3500 GWh to 3800 GWh. The annual production of thermal energy for remote heating of the Šaleška valley is from 400 GWh to 450 GWh. For the abovementioned production of electricity and thermal energy, from 3.5 to 4.2 million tons of coal and around 60 million m³ of natural gas is used every year, [12].

Table 1: *Specified power of generators [12]*

Block	Fuel	Specified power of generators
Steam block 1	Lignite	Permanently halted on 31 March 2010
Steam block 2	Lignite	Permanently halted in 2008
Steam block 3	Lignite	75 MW (to be permanently halted in 2015)
Steam block 4	Lignite	275 MW (to be permanently halted in 2015)
Steam block 5	Lignite	345 MW (to be permanently halted in 2027)
Two gas blocks	Natural gas	2 × 42 MW (permanently halted in 2027)

After the acceptance of the Strategic Development Plan of TEŠ in June 2004, Block 6, with 600 MW, power will gradually replace the technologically outmoded and economically unprofitable Blocks 1, 2, 3, 4 and 5. This is a nationally important project, which the government accepted on 12 October 2006 and amended in 2008. It is a part of the Resolution of the National Energy Programme and of the Resolution of National and Development Projects for the period from 2007 to 2023. For the same amount of produced energy, Block 6 will use approximately 30% less coal, thereby significantly lowering emissions, [12].

Thermoelectric plant Toplarna Ljubljana (TE-TOL)

TE-TOL is the largest combined heat and power generation in Slovenia. It supplies more than 90% of the needs of the remote heating system of Ljubljana, which represents approximately 50% of such needs for Slovenia, [13]. The electricity produced represents 3% of the needs for electricity in Slovenia.

Table 2: *Specified power [13]*

Block	Fuel	Specified power of generators	Specified thermal power
Steam block 1	Brown coal	42 MW	94 MW
Steam block 2	Brown coal	32MW	94 MW
Steam block 3	Brown coal Biomass	50 MW	152 MW
LPB	Oil		150 MW

Since 2002, only Indonesian coal (low sulphur content) has been used in TE-TOL, because of the requirements of ecological legislation. The coal must have a high heating value and low sulphur content (under 0.2%) and ash (1–3%), [13]. Otherwise, the company would have to invest in expensive technology for cleaning emissions. In the boiler of Block 3, wood chips also have been used since 2008, replacing 20% of the coal. From renewable energy sources, approximately 8% of thermal energy and electricity is produced.

From 1 January 2016 onward, TE-TOL will not be able to achieve the allowed emission of carbon dioxide (200 mg/m^3); its average annual concentration around 400 mg/m^3. With the transitional national plan, in which TE-TOL was included in December 2012 and is valid until 1st July 2020, the company will change the primary fuel from coal with natural gas. This gasification phase (PPE-TOL) is one of the measures in the transitional national plan of Slovenia.

Thermoelectric plant Trbovlje (TET)

TET is the largest energy facility in the Zasavje region. Together with the Zasavje coal mines, it had been a key element for the development of many factories, industrial and craft plants, traffic and social services in Zasavje and Slovenia. TET currently has two units; the steam block produces electricity from brown coal from the Zasavje coal mines, while the two gas blocks use natural gas and oil for the production of electricity; they are a reserve in the electrical energy system of Slovenia. TET sells the remaining amount of electricity independently on the market, [14].

Table 3: *Specified power of generators [15]*

Block	Fuel	Specified power of generators
Steam block	Brown coal	125 MW
Two gas blocks	Oil	Complete power 63 MW

The vision of TET is the construction of a gas-steam electric power plant that has the possibility of being upgraded with an integrated gas combination cycle, which requires the gasification of coal or fuel oil as remainder in the process of refining oil and the implementation of neutralization technology of greenhouse gases. This vision also requires the renovation of gas blocks with a combined coal and wooden biomass unit with the possibility of using the heat energy for the heating of Zasavje. With the renovation of the gas blocks, the extraction of coal from the Trbovlje-Hrastnik coal mine would be extended, or the coal would have to be substituted by imports.

Thermoelectric plant Brestanica (TEB)

TEB provides reliable and safe electricity production, with the aim of remaining the leading provider of systemic services of tertiary regulation while simultaneously being an indispensable reserve electricity source for the Krško nuclear power plant. With its services, TEB is a reliable reserve electricity source for the electrical system of Slovenia at its most critical moments. With its fast aggregates, the plant enables rapid intervention at times of system overload or a cut out of Slovene electric power plants or power lines, thereby preventing collapses of the electrical energy network with quick intervention, restructuring of the electrical energy network after a failure, and providing an independent and direct energy source for the Krško nuclear power plant, [16].

Table 4: *Specified power of generators [16]*

Block	Fuel	Specified power of generators
Three gas blocks	Oil or natural gas	3 × 23 MW
Two gas blocks	Oil or natural gas	2 × 114 MW

The policy of the company is to keep or to increase its share of the market of systemic services of tertiary regulation on the domestic and foreign electricity markets, to optimise business costs, to provide high start-up reliability and availability of company devices, to continue with its active role in the maintenance chain of hydroelectric power plants on the lower River Sava and to maintain a quality system according to the ISO 9001 standard. Its purpose is to continue with the substitution of gas blocks with 3 × 23 MW power with new blocks, which will correspond both to ecological standards and the technical demands of tertiary regulation, and quick start up in the case of a collapse of the electrical networks, [16].

3 CONCLUSION

With the increasing population, development and economic growth, the need for energy has also increased. From a global perspective, energy needs are currently very different from continent to continent. The largest increase is in the developing economies of China and India. The biggest energy needs but with rather moderate growth is seen in the USA. European needs are decreasing somewhat, which is connected with economic indicators. The world is becoming increasingly ecologically conscious; consequently, environmental legislation, which is based on decreased emissions of greenhouse gases and environment protection, is of key importance. From a global perspective, the human factor represents only 4% of carbon dioxide emissions into the atmosphere. The warming of the oceans represents the largest part, i.e. 90%, of the increase of carbon dioxide concentration in the atmosphere. When the oceans' temperature decreases, carbon dioxide is absorbed, but when the temperature rises, carbon dioxide is released. Human use of energy, therefore, contributes only a small part of greenhouse gases; the rest is a consequence of the natural warming of the atmosphere (solar radiation, protective ozone layer, etc.). Nevertheless, environmental legislation forces the energy industry to buy new and more expensive technologies or to buy emission quotas. The global, European and Slovene energy industries have adjusted to the environmental guidelines with lower coal usage and greater usage of natural gas. The thermal energy industry of Slovenia uses both energy sources for the production of thermal energy and electricity in rather old and obsolete systems. In the transitional period until 2020, fundamental changes must occur, which will be seen in the closing of coal thermoelectric plants and investments into gas thermoelectric plants. The reason for this is also the closing of coal mines in Slovenia, as from 2015 only the coal mine in Velenje will be in operation. This, however, means that Slovenia will be increasingly dependent on imports. We will be able to import the energy sources in the primary form (coal, gas, oil) or as a final product in the form of electricity.

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Nomenclature

CO_2	Carbon dioxide
EIA	U.S. Energy Information Administration
EUROSTAT	European Commission Statistic
GWh	Giga Watt Hour
IEA	International Energy Agency
MW	Mega Watt
Mtoe	Million Tonnes of Oil Equivalent
NEP	National Energy Programme of Slovenia
LPB	Low Pressure Boiler
PPE-TOL	Toplarna Ljubljana gas-steam energy source
RS	Republic Slovenia
SURS	Statistical Office of Slovenia
TEB	Brestabica thermoelectric plant
TWh	Tera Watt Hour
TE-TOL	Toplarna Ljubljana thermoelectric plant
TEŠ	Šoštanj thermoelectric plant
TET	Trbovlje thermoelectric plant

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A CASE STUDY OF EXERGY ANALYSIS OF WASTE HEAT RECOVERY IN REFRIGERATION SYSTEM

ANALIZA EKSERGIJSKIH TOKOV V HLADILNEM SISTEMU Z IZKORIŠČANJEM ODPADNE TOPLOTE

Ivana Tršelič[ℜ], Jurij Avsec

Keywords: exergy analysis, refrigeration system, waste heat recovery

Abstract

From an energy perspective, refrigeration systems employ a wasteful process; nevertheless, the food industry depends on refrigeration systems. To improve the efficiency of this process, a refrigeration system can be combined with a heating system, by using the waste heat from the condenser of the refrigeration system in the heating system. A case study of the application of a waste heat recovery system is considered in this paper. The conserved energy for three years is calculated, based on the literature, i.e. practical engineering articles. The numbers given are compared with the case study. The economic analysis reveals that the investment in an advanced refrigeration system is returned over a very short time. Two system models are discussed: a refrigeration system with no alternation and a refrigeration system that applies the recovery of waste energy. Exergy analysis has been developed for both models. The analysis shows an increase in the exergy efficiency of the advanced refrigeration system by 2%.

Povzetek

Z vidika porabe energije je hladilni sistem zelo potraten. Industrija hrane je odvisna od hladilnih sistemov. Proces hlajenja lahko naredimo bolj učinkovit tako, da izkoriščamo odpadno kondenzator-

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sko toploto. Opazovali smo konkreten primer na katerem smo sistem izkoriščanja odpadne toplote inštalirali. Izračunali smo izkoriščeno odpadno toploto v zadnjih treh letih delovanja sistema. Enačbe za preračun izrabljene odpadne toplote smo našli v starejši literaturi. Ekonomska analiza pokaže, da se začetna investicija povrne v zelo kratkem času. Z eksergijsko analizo sistema brez izkoriščanja odpadne toplote in sistema z izkoriščanjem odpadne toplote smo ugotovili, da ima slednji za 2% boljši eksergijski izkoristek.

1 INTRODUCTION

Refrigeration chambers maintain foodstuffs at a particular temperature in order to extend the shelf life of foods. This paper deals with an exergy analysis of cold storage intended for freezing fish. The refrigeration chamber cooling system maintains a constant temperature by supplying cold through evaporators, thus compensating for heat losses through the refrigeration chamber walls or due to the impacts of lighting fittings, occasional opening of the door, etc. The refrigeration system is wasteful in terms of energy consumption. From an energy perspective, the upgrading the refrigeration system, involving the capturing of waste heat from the condenser to use the hot side of the cooling system, results in a greater effect, lower energy consumption and, ultimately, financial savings.

Modern refrigeration rooms and cold stores are designed to freeze the largest possible quantity of food in the shortest time possible. This case study involves the storage of fish; freshly caught fish, a highly perishable food, should be stored in a flake ice bath, while frozen fish is stored in frozen fish chambers until taken over by a customer. Refrigeration tunnels operate when necessary, but the storage rooms have to maintain a constant temperature throughout the year. In terms of energy consumption, contemporary systems include new compressor designs with a so-called integrated eco-system, reducing isentropic losses by cooling hot gases during compression and installing a sub-cooler on the condenser side to increase the evaporator cooling power, using little energy. The use of condenser heat is necessary in order to increase the efficiency of the refrigeration system.

This article deals with the calculation of savings, whereby the amount of heat recovered from the condenser unit is based on the equations found in articles by Die Klima und Kaeltetchnik, published in 1987, [1]. The exergy analysis of the upgraded system proves the improvement of refrigeration systems to be reasonable.

2 REFRIGERATION SYSTEM DESIGN

The refrigeration system observed consists of five refrigeration units, the first of which is designed to maintain the temperature of the chambers with the packaging, and a corridor designed for handling. The second unit maintains the temperature of the chambers containing frozen fish. The third cooling unit operates occasionally, as it ensures the functioning of the refrigeration tunnels, freezing approximately 10 tons of fresh fish to -28°C in nearly nine hours of operation. The fourth unit also operates occasionally, producing flake ice. The fifth refrigeration unit operates separately, when necessary. It allows the freezing of each fish separately, [2].

For waste heat recovery from condensers, only those systems that operate constantly throughout the year may be used. These maintain a constant temperature in the refrigeration chambers.

The first system maintains a constant temperature in the fresh fish chambers and operates at an evaporation temperature of +3°C or -8°. A suction pressure regulator needs to be fitted to the suction pipes of the chambers with the evaporation temperature of +3°C. This system is referred to below as the ‘plus system’.

The second system, maintaining a constant temperature in the frozen fish chambers, operates at evaporation temperatures of -32°C or -13°C. In this case, a suction pressure regulator is also needed to maintain the evaporating temperature of -32°C in the suction pipe. This system is referred to as the ‘minus system’.

The plus system comprises six chambers connected to a compressor set with three compressors. These are four-piston compressors with a two-stage regulation of the operation. The regulation may be performed at six stages. The plus system’s cooling capacity is 57 kW, and the condensation heat to be recovered from the system is 77 kW, [2].

The minus system comprises five chambers connected to a generator unit with 2 six-piston compressors, each capable of performing a three-stage regulation. The minus system’s cooling capacity is 47 kW and the condensation heat 78 kW, [2].

2.1 Waste heat recovery system

While the condensation temperature of the designed system is 45°C, the hot gases exiting the compressor have a temperature of 76°C. It is established that tap water can be heated from 10°C to 50°C for sanitary use with an additional plate heat exchanger installed before the hot gasses enter the air-cooled condenser.

In accordance with Die Kaelte und Klima Technik, [1], an analysis of possible waste heat recovery systems was made to select an appropriate plate heat exchanger. The decision was made to connect the pressure pipes from the plus system’s multi-compressor unit and the minus system’s multi-compressor unit with regard to the position of the engine and boiler rooms.

A 40 kW plate heat exchanger is installed in the engine room, using part of the condensation heat of the refrigeration system in question for heating the sanitary water, presented in Fig. 1, before entering the condenser, placed on the roof. Water travels through the plate heat exchanger and transfers heat to the heating system in the boiler room as shown in Fig. 2. The selected condenser is of sufficient size to be able to evacuate condensation heat from the refrigeration system even when the waste heat recovery system is inactive.

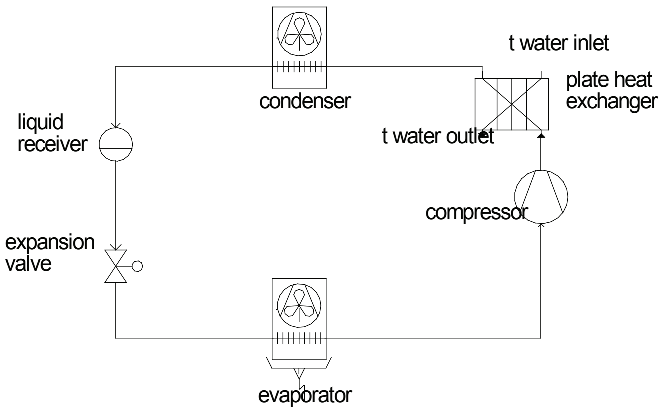

***Figure 1:** Refrigeration system with waste heat recovery [2]*

2.2 Boiler room design

The boiler room is located away from the engine room, which is a weakness of the system, as some heat is lost during distribution. The boiler room houses a 500-litre tank, receiving heat by the bottom coil from the waste condensation heat recovery system shown in Fig. 2. The tank is used only for sanitary water in toilets of the office part of the building, in the staff kitchen and bathroom. Tap water is used for the purposes of building cleaning.

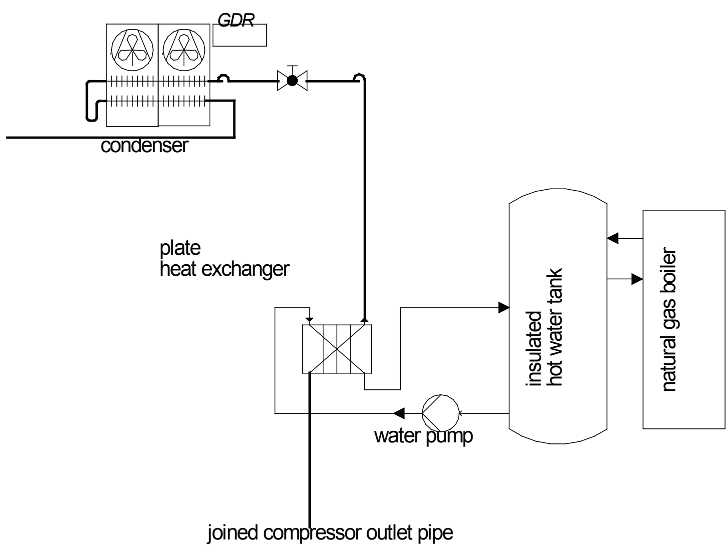

***Figure 2:** Waste heat recovery system combined with the heating system [2]*

3 CALCULATION OF WASTE HEAT

The plate heat exchanger, installed as indicated in (Fig. 1), initially recovers the heat occurring in hot gas cooling and then recovers a portion of the heat dissipated in the refrigerant condensation.

To analyse the system, the equations for the calculation of the quantity of condensation waste heat that can be recovered were needed. The equations according to [1] were used, showing that the recovered condensation waste heat is calculated according to Equation 3.1, in which Δh_2 and Δh_1 are the values from the diagram log p – h (Fig. 3).

$$\dot{Q}_w = \dot{Q}_{cond} \cdot \frac{\Delta h_2}{\Delta h_1} \tag{3.1}$$

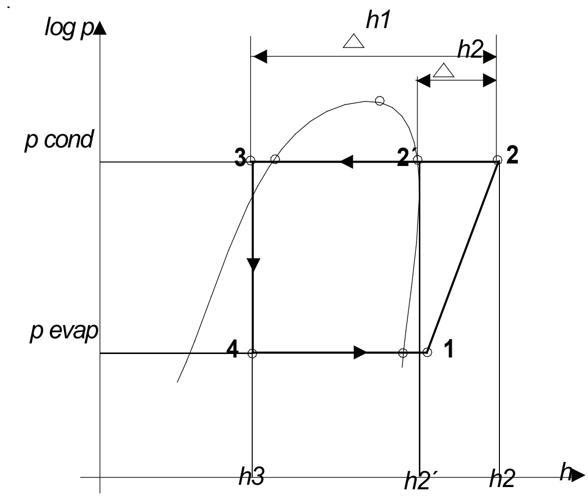

Figure 3: *Values used for the calculation of waste heat [2]*

Given that the waste heat recovery system comprises both the plus and the minus system, separate calculations are required.

3.1 Calculation of waste heat for the plus system

For the given state of operation, the values of enthalpy in the working points were read from the log p – h diagram for Freon R404A [3] and presented in Table 1.

Table 1: *Values of enthalpy used in the calculation for the plus system*

	h (kJ/kg)
h_2	405
$h_{2'}$	380
h_3	265
Δh_1	140
Δh_2	25

Using (3.1), it was calculated that 13.7 kW of waste heat flow may be recovered from the plus system.

3.2 Calculation of waste heat for the minus system

For the given state of operation, the values of enthalpy in the working points were read from the log p – h diagram, for Freon R404A, [3], and are presented in Table 2.

Table 2: *Values of enthalpy used in the calculation for the minus system*

	h (kJ/kg)
h_2	418
$h_{2'}$	380
h_3	266
Δh_1	152
Δh_2	38

Using (3.1), it can be calculated that 19.5 kW of waste heat flow may be recovered from the minus system.

The total waste heat flow that can be recovered for sanitary water heating purposes is 33.2 kW.

As (3.1) was only found in older references and the use of condenser waste heat had become common knowledge over years of practice, the calculation of its amount with (3.1) became a useful instrument.

4 CALCULATION OF COST SAVINGS

Waste heat recovered from a refrigeration system operating 3,900 hours per year amounts to 129,480 kWh, [2]. According to (4.1), the amount of heated water can be calculated.

$$\dot{V} = \frac{\dot{Q}_w}{c_p \cdot \Delta t \cdot \rho} \tag{4.1}$$

Over a period of one year, the refrigeration system can heat approximately 2,774 m^3 of tap water from 10°C to 50°C using the condensation heat. In order to heat the same amount of water, the quantity of 11,262 m^3 natural gas would be required. In three years, the cost saving would account for €16,724 when calculated with the average natural gas price over the last six years, i.e. €0.495 for 1 m^3.

In view of the fact that the consumers in the building need a lower quantity of waste heat, it is established that they do not need a gas boiler for sanitary water heating. The given refrigeration system contains a sufficiently high quantity of waste heat for heating the sanitary water.

The price for one extra plate heat exchanger, extra valves, and tubes is approximately €7,500. The diagram presented in Fig. 4 shows the number of months in which the investment repays its costs over savings, taking in account the price variable for 1 m^3 of natural gas over the previous six years.

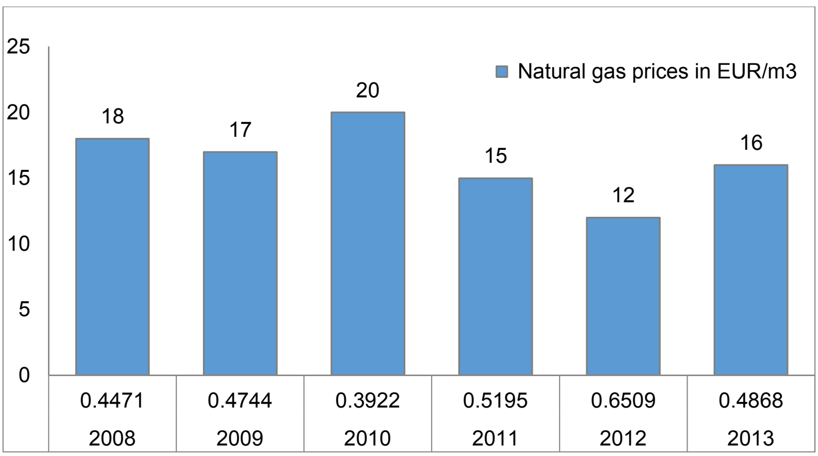

Figure 4: *The number of months to repay investment over savings*

5 EXERGY ANALYSIS OF THE REFRIGERATION SYSTEM

The cost-benefit analysis has revealed that upgrading the refrigeration system is financially viable. Given that energy may be used for refrigeration and heating, it may be argued that the upgrading results in an increase in the exergy of the system.

The exergy method is a functional means of promoting the effectiveness of energy-resource use, [4]. To begin the calculation, the specific exergy was calculated using (5.1).

$$e = (h - h_0) - T_0(s - s_0) \tag{5.1}$$

where h_0 and s_0 are specific enthalpy and enthropy at surroundings temperature, respectively, [4].

For each state, the values in Table 3 were used.

Table 3: *Values of specific enthalpy, specific entropy [3] and calculated specific exergy calculation (5.1) for the plus system*

	State	h (kJ/kg)	s (kJ/kgK)	e (kJ/kg)
0	Surroundings	395	1.854	0
1	Compression start	368	1.636	37.17
2	Condensation start	405	1.659	67.13
3	Expansion start	260	1.198	57.03
4	Evaporation start	259	1.225	48.57

To calculate the exergy efficiency of the system, the equations according to [5] were used.

5.1 Exergy losses in a compressor

Exergy losses in a compressor occur due to electromechanical conversion and isentropic efficiency compression and can be calculated using (5.2).

$$e_{comp} = (1 - \eta_{em}) \cdot e_{in} + \eta_i \cdot e_{in} + e_1 - e_2 \tag{5.2}$$

For 90% electromechanical conversion efficiency and 80% isentropic compression efficiency in a compressor, a 21.7% loss was calculated regarding the exergy when entering the system.

5.2 Exergy losses in an evaporator

Evaporators are units through which the supplied exergy is lost due to the mass flow and is calculated using (5.3).

$$e_{evap} = e_4 - e_1 - e_{cold} \tag{5.3}$$

The exergy loss due to the mass flow rate accounts for 29.8% of the supplied exergy. An evaporator is a working unit that evacuates the heat from a room. Therefore, the percentage of the exergy loss is reduced by thermal exergy of the heat which is transferred from the chamber.

Thermal exergy load of heat is calculated using (5.4), [6].

$$e_{cold} = q_{evap} \cdot \left(1 - \frac{T_0}{T_{INsr}}\right) \tag{5.4}$$

Where the surroundings temperature T_0 of 293 K and T_{INsr} mean temperature of the air into which the evaporator dissipates the heat out of the chamber, the value of 270.5 K, were used. The total exergy loss through the evaporator is 5.5% of the inlet exergy. The exergy of heat inlet in the evaporator is 24.3%.

5.3 Exergy losses in an expansion valve

The exergy loss is calculated using (5.5) in an expansion valve, where an adiabatic system conversion takes place, solely in terms of the exergy supplied and recovered.

$$e_{exp} = e_3 - e_4 \tag{5.5}$$

The calculated loss of the exergy supplied to the expansion valve is 22.1%.

5.4 Exergy losses in a condenser

The loss of exergy through an air cooled condenser comprises the supplied and recovered exergy flow through the condenser (5.6).

$$e_{cond} = e_2 - e_3 \tag{5.6}$$

It was calculated that 26.4% of the supplied exergy is lost in the condenser.

Exergy losses and gain are presented in Table 4 and in (Fig. 5) according to Rant, [7].

Table 4: *Values of exergy inlet losses and gains*

	Exergy loss (%)
Compressor	21.7
Expansion valve	22.1
Evaporator	5.5
Condenser	26.4
	Exergy gain (%)
Heat outlet of the chamber	24.3

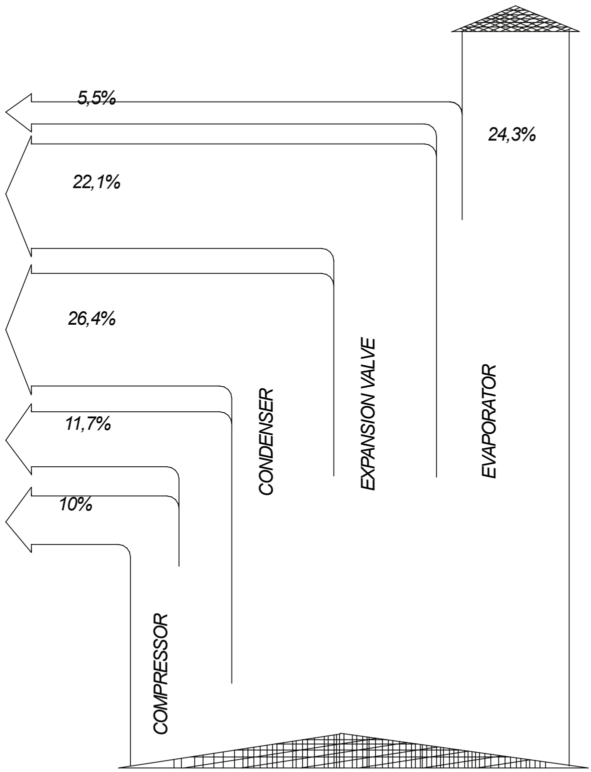

Figure 5: *Exergy Rant diagram for refrigeration system*

6 EXERGY ANALYSIS OF THE REFRIGERATION SYSTEM UPGRADED WITH HEAT RECOVERY

In the refrigeration system upgraded with a waste heat recovery, the percentage of the lost exergy through the condenser is changed, as a portion of exergy is recovered in the form of heat for heating purposes.

The calculation of the exergy loss in the condenser was repeated, due to added state of calculation values to Table 3, and are presented in Table 5.

Table 5: *Values of specific enthalpy, specific entropy [3] and calculated specific exergy calculation (5.1) for the plus system upgraded with heat recovery*

	State	h (kJ/kg)	s (kJ/kgK)	e (kJ/kg)
0	Surroundings	395	1.854	0
1	Compression start	368	1.636	37.17
2	Heat recovery start	405	1.659	67.13
2'	Condensation start	383	1.588	65.94
3	Expansion start	260	1.198	57.03
4	Evaporation start	259	1.225	48.57

6.1 Exergy losses in a condenser of the system using waste heat

The exergy losses in an air cooled condenser are calculated using (6.1). As before, exergy is lost due to the mass flow, but the losses are considered at the flow through state 2.

$$e_{cond} = e_{2'} - e_3 \tag{6.1}$$

The exergy loss due to the mass flow amounts to 23.3% of the supplied exergy in the system.

In a plate condenser, in which heat is recovered to the sanitary water heating system, a portion of exergy is used for heating. Given that a plate heat exchanger is also a unit causing specific exergy losses due to the mass flow, this portion of the lost exergy should also be taken into consideration.

Thermal exergy load of heat calculated with (6.2) according to [6].

$$e_{heat} = q_w \cdot \left(1 - \frac{T_0}{T_{OUTsr}}\right) \tag{6.2}$$

Where T_0 is the surroundings temperature of 293 K and T_{OUTsr} value of 303 K is median temperature of water into which the condenser dissipates the heat. Thermal exergy through the plate heat exchanger is 2% of the inlet exergy, whereas the exergy loss due to the mass flow through the plate heat exchanger, calculated with (6.3), is 3.1% of the exergy inlet.

$$e_w = e_2 - e_{2'} \tag{6.3}$$

Altogether, the exergy loss through the plate heat exchanger is 1.1% due to exergy loss reduction by 2%. The waste heat recovery system represents the possibility of increasing the exergy of the refrigeration system. Exergy losses and gains are presented in Table 6 and in (Fig. 6) according to [7].

Table 6: *Values of exergy inlet losses and gains for heat recovery*

	Exergy loss (%)
Compressor	21.7
Expansion valve	22.1
Evaporator	5.5
Condenser	26.4
Plate heat exchanger	1.1
	Exergy gain (%)
Heat recovery	2
Heat outlet of the chamber	24.3

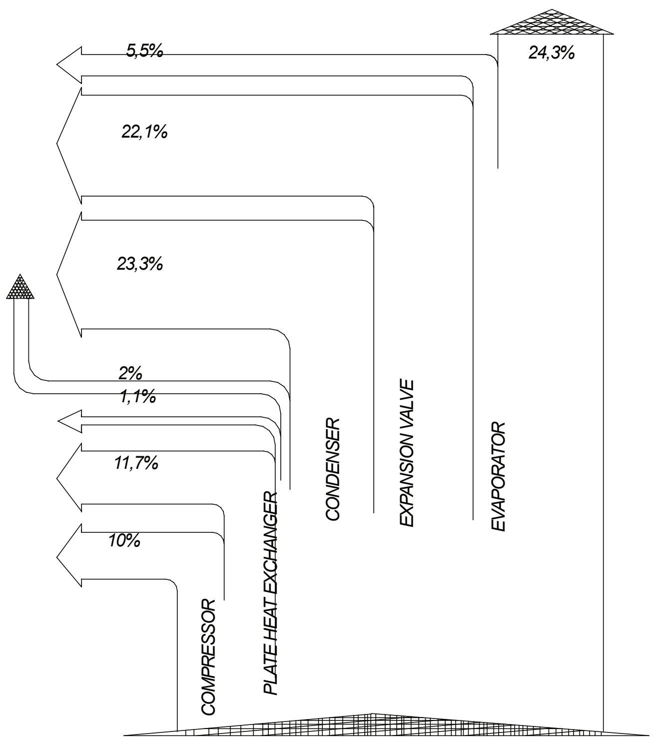

Figure 6: *Exergy Rant diagram for refrigeration system with heat recovery*

7 CONCLUSION

This case study shows the quality of refrigeration project applicable in all constant operating refrigeration systems with higher condensation temperatures. To avoid problems with Legionella infections, additional heaters need to be installed.

The exergy calculations of both systems show that the exergy efficiency is increased in the waste heat recovery system. It is also more efficient from an energy perspective. The cost-benefit analysis shows that via a small additional contribution and a proper selection of components it is possible to influence the long-term efficiency of the system. The waste condensation heat recovery systems are simple, and it is reasonable to use them in a refrigeration system operating throughout the year. The investment pays off approximately in one year.

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Nomenclature

e	specific exergy
h	specific enthalpy
Q_w	waste heat
Q_{cond}	condensation heat
s	specific entropy
Δt	temperature difference
T_0	environment temperature
T_{INsr}	median temperature in the evaporator
T_{OUTsr}	median temperature in the condenser
V	volume flow
η_{em}	electromechanical efficiency
η_i	isentropic efficiency

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RENEWABLE ENERGY POTENTIAL AND OPPORTUNITIES FOR ORGANIC FARMING IN THE REGION OF THE ŠALEK VALLEY

OBNOVLJIVI ENERGETSKI POTENCIALI IN SONARAVNO KMETIJSTVO ŠIRŠEGA OBMOČJA ŠALEŠKE DOLINE

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Keywords: food production, organic farms, renewable energy, rural landscape, sustainable farming, Šalek Valley

Abstract

The purpose of this research paper is to examine the rural area of the Šalek Valley and to determine what the potential for the promotion of organic farming is in an area that is traditionally better known as an electricity producer and industry supplier. The predominant agricultural activity is livestock, and there is almost no market-oriented horticulture. The farms included in the study were from three neighbouring municipalities: Velenje, Šoštanj and Šmartno ob Paki; 1218 farm owners were invited to participate, and the research was presented orally to 370 farmers. Only 40 surveys were returned and completed; nine of these were declared to be organic farms and four to farms in conversion. The average age of the surveyed farm owners was over 50 years and was not significantly different regarding the farms' orientation; 63% of family farms have already planned for a successor, less so with the organic agricultural holdings. Since organic farms also showed livestock to be the predominant agricultural activity, a good potential for the renewable (biomass) energy production, e.g. co-generation of electricity and heat, was assumed.

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As we were interested in the economic prospects of the farms, we wanted to know their attitude to energy supply as a supplementary farm activity or whether they had had any experience with renewable energy sources.

With these input data, we want to check: a) agricultural holdings, especially those that were organic-oriented, which are expected to have the prominent role in the future food supply; b) how the owners plan the on-farm activities; and c) the current energy supply and openness of farmers to using other energy sources.

Povzetek

Uvodoma smo želeli preučiti lokalno ponudbo podeželja Šaleške doline in ugotoviti možnosti za pospešitev razvoja ekološkega kmetijstva na območju, ki je tradicionalno bolj znano kot območje termoenergetike in industrije. V raziskavo so bile zajete kmetije 3 občin: MO Velenje, občine Šoštanj in občine Šmartno ob Paki. K sodelovanju je bilo povabljenih 1218 nosilcev kmetijskega gospodarstva, od tega je bila 370-tim kmetijam raziskava predstavljena še ustno. V raziskavi je sodelovalo 40 kmetijskih gospodarstev, od tega 9 ekoloških in 4 integrirane kmetije. Povprečna starost nosilcev kmetijskega gospodarstva v Šaleški dolini je nad 50 let in se ne razlikuje pomembno med ekološko usmerjenimi in ostalimi kmetovalci. Na 63 % kmetijah je že znan naslednik, na registriranih ekoloških kmetijah je odstotek manjši. Ker tudi na ekoloških kmetijah prevladuje živinorejska usmerjenost, predvidevamo še neizkoriščene možnosti za uporabo biomase (organskih odpadkov) za namen proizvodnje obnovljive energije, tudi v obliki kogeneracije električne in toplotne energije.

V nadaljevanju nas je zanimala ekonomska perspektiva kmetij, kako razmišljajo o energetski preskrbi kot dopolnilni dejavnosti kmetije, kakšno je njihovo mnenje ali že izkušnja z obnovljivimi viri. Z omenjenimi vhodnimi podatki želimo preveriti: a) usmerjenost kmečkih gospodarstev, predvsem ekoloških, od katerih se v prihodnje pričakuje vidnejša vloga v prehranski preskrbi, b) kako nosilci kmetij načrtujejo proizvodne dejavnosti na kmetijskem gospodarstvu ter c) aktualno energetsko oskrbo in odprtost kmetovalcev za koriščenje drugih energentov.

1 INTRODUCTION

The transformation of conventional farms to organic farming is an appropriate goal, which also coincides with European agricultural directives and ensures a monitored food network, safe food, the revitalization and strengthening of rural areas and healthy ecosystems. Many potentials for organic farming and local food supply have been studied (Slabe et al., 2011):

- to increase supply of Slovene organic products (especially vegetables and fruit), direct sales at farms and agricultural holdings of larger size should be encouraged,
- obstacles to producers in terms of cooperation and market connections should be removed,
- more knowledge transfer at production and market areas should be supported and realized.

The goal of developing sustainable agriculture is the responsibility of all participants in the system, including farmers, workers, policy makers, researchers, retailers and consumers. Each group has its own part to play and its own unique contribution to strengthen the sustainable agriculture community (De Lauwere et al., 2004).

The number of organic farms in Slovenia has been increasing; in 2005 1.6% of family farms declared themselves to organic; by 2010, that number has risen to 2.5%. In addition, 0.4% farms were in the process of conversion (Agriculture Census, 2010). Among gainful activities on family farms, renewable energy production is a promising supplementary activity, with regard to the increasing number of farm families in recent years (Table 1).

Table 1: *Complementary activities on family farms (in number), Slovenia, 2000–2010.*

Supplementary activity/year	2000	2010	Index $_{(2010/2000)}$
Meat processing	221	155	70.14
Milk processing	247	242	97.98
Fruit and vegetable processing	394	502	127.41
Farm tourism	692	642	92.77
Renewable energy production	38*	78	205.26
Handicraft	268	167	62.31
Aquaculture	75	28	37.33
Sale of wood products	104	28**	26.92
Forestry	-	9078	-
Wood processing	699	513	73.39

(Source: SORS, 2013)

Legend: * data values for 2003; ** data values for 2007; - no data

Further, we attempted to make some common findings between food production on agricultural holdings and their openness to using renewable energy sources.

Before the project (European Agriculture Fund for Rural Development), there was no information on the food supply characteristics and the prevalence of organic farming in the Šalek Valley. The original idea of the research was to present it to the food-producing farms and help them in connecting and communicating with the local people who are interested in organic-produced and healthy food supply of local origin.

We were following these project goals:

1. to check the farmers' marketing interests, collect data on farms' locations and their supply at home for potential buyers,
2. to enable farmers to sell their products directly to consumers interested in safe food consumption,
3. to connect the organic farmers with the potential clients, and
4. to verify the status of the use of renewable energy sources.

The project was focused on organic food production and processing, in the local environment and directly accessible to local people. The research goals were to involve and promote farms that have already introduced the organic food production guidelines. The results should have encouraged the majority of farmers in the valley that use conventional work methods, i.e. following the European and national guidelines, and guiding producers and consumers to full local food self-sufficiency.

Indirectly, we intended to educate young people, future consumers and potential actors in organic farming. At the same time, farmers were introduced to renewable energy production, and we noted that a workshop on this topic would be very welcome by them.

We wished to inspire farmers for organic food production and the acceleration of sustainable farming with other supplementary activities, especially in the areas with limited factors for farmland (mostly steep terrain with a prevailing share of grassland), which would help to revitalize the agricultural landscape of the Šalek Valley.

2 AREA OF RESEARCH

2.1 Agriculture and land use in the researched area

The Statistical Office of the Republic of Slovenia data, published in Statistical GIS land cover of Slovenia, showed the spatial distribution of the cover categories and the decreasing of the rural land between 1993 in 2001 (SORS, 2013). The precise structure of agricultural land database in 2001 reports that the biggest share in the Savinjska statistical region belongs to meadows (25.9%) and only 3.2% to arable land. In the evidence of the last observation period (2011), the share of forest land had the same value as in previous periods, the increase (+3.2%) of the agricultural area was surveyed and developed areas in the region expanded by 2.6%. The register of the actual land use of agricultural and forest land for 2005 and 2011 showed more extensive farming in the region (the meadows' share rose up from 22.3% of the total agricultural land in 2005 to 24.8% in 2011 (Table 2).

Table 2: *Land cover of the chosen categories in shares (%), Savinjska statistical region, 1993–2011.*

Year/Category	Wooded areas	All agricultural areas	Developed areas
1993	55.2	39.8	3.1
1997	56.7	37.3	3.2
2001	60.9	32.9	3.3
2005	57.5	34.1	6.7
2011	56.7	36.1	5.9

(Source: Statistical Year book…, 2011; Analiza stanja ekološkega…, 2013)

In 2007, approximately 4.9% of employed Slovenians worked in agriculture. In Table 3, we can see the data of the same period (2007) for the researched area; the municipality of Šoštanj (7.7%), Šmartno ob Paki (10.6%). Meanwhile, the municipality of Velenje had a strong focus on employment in other sectors. A comparison with the surveyed data from 2002 showed a positive employment trend in agriculture, but not in Slovenia as a whole.

Table 3: *Share (in %) of the persons employed in agriculture.*

Municipality/Year	2002	2007	2011
Šmartno ob Paki	4.08	10.6	11.0
Šoštanj	5.71	7.7	5.5
Velenje	0.99	1.3	1.5
Slovenija (average)	5.5	4.9	3.6

(Source: Statistical Yearbook ..., 2011)

Regarding the change of number of people employed in agriculture, between 2007 and 2011 a slight increase was recorded in Velenje and Šmartno ob Paki, whereas the value of the Šoštanj returned to the state in 2002 (Table 3). The average Slovene share was steadily declining.

Considering the possibilities for more promising and profitable farming with sustainable methods, the availability and quality the land resources is important. The Statistical Office of RS data for the year 2000 confirms extremely dispersed agricultural land in Slovenia (SORS, 2013). The share of the smallest agricultural holdings was the highest. Only Šoštanj exceeded the Slovenian average with 6.1% in the largest agricultural holdings (over 10 ha) category; the other two municipalities were below average. By the year 2010 the share had dramatically changed; the lowest data were shown in Velenje whereas farms in Šoštanj had 60% in the largest size class (over 10 ha).

Table 4: *Share (in %) of the agricultural holdings by size classes of utilised agricultural area (UAA) in 2000 and 2010.*

Municipality/ size/year	0 - < 2 ha		2 - < 5 ha		5 ha - < 10		> 10 ha	
	2000	2010	2000	2010	2000	2010	2000	2010
Šmartno ob Paki	36.9	9.42	36.9	23.5	20.0	26.9	6.25	40.07
Šoštanj	27.7	3.38	26.1	10.0	27.4	26.28	18.7	60.3
Velenje	28.4	5.8	38.3	29.9	25.0	40.25	8.3	30.8
Slovenija	26.6	4.6	35.2	17.5	25.5	25.9	12.6	51.9

(Source: Agriculture Census 2010; SORS; 2013)

3 METHODOLOGY

After collecting and examining the statistics, the fieldwork provided basic input data for research, since we wanted to determine the actual characteristics that formed agriculture in Šalek Valley. Only the description questions in the interview yielded information about the opinion, values and points of view of the farms' owners. We planned to check the following topics:

- Are organic farms in average smaller than conventional/in conversion farms?
- Are the owners of the organic farms younger or more educated than owners of the conventional/in conversion farms?
- Do organic farms practice electricity production from renewable sources on a larger scale than conventional/in conversion farms?

The extensive content of the survey consisted of basic contact information of the farm, land use, livestock, evidence of the production of market vegetables, renewable energy production, persons in employment at family farms, forestry at farms, fish farming, tourism and other supplementary activities at farms, organic farming and biodynamic agriculture, permaculture and beekeeping. We attempted to include all fields of agriculture. There were no answers about fish farming, and very little interest was evident regarding beekeeping. Finally, we checked the farm managers' interest in renewable sources use.

4 RESULTS AND DISCUSSION

4.1 Agricultural holdings by size

Nine organic farms were included in the survey. The total area of their farmland was 459.8 ha. We also interviewed four farms in conversion, with a total of 59.3 ha. The average organic farm size was 26.23 ha, excluding one extremely large farm with over 350 ha (with rented land outside the surveyed area). The farms in conversion had an average of 18.83 ha large, and the conventional farms had an average of 25.93 ha.

Table 5 shows the administrative distribution of the family farms and the type of farming. Only some of them (15%) have registered the supplementary activities to their basic agricultural orientation.

Table 5: *The researched family farms considering the municipality affiliation and type of farming.*

Production/Municipality	Šoštanj	Šmartno ob Paki	Velenje	Total
Vegetables /fruit		1	1	2
Meat/milk	1			1
Sheep	2			2
Mixed		2	2	4
Vegetables /fruit		2	2	4
Meat/milk				
Mixed				
Vegetables /fruit	1		2	3
Meat/milk	4	3	6	13
Tourism	3		2	5
Other farms	beekeeping, winery, cereals – bakery products	2	solar cells	6
Total	14	10	16	40
Key	conventional farms	organic farms	farms in conversion	

The average farm size in the research area was 24.23 ha; in contrast, the average Slovenian farm size in 2010 was 6.4 ha, i.e. 18.45 ha less than our researched farms. The average farm in the Savinjska statistical region had 5.9 ha in the same period (Agriculture Census, 2010).

We recorded an organic farm owner that was distinct in its size, consisting of eight agricultural holdings located across the western part of the Savinjska statistical region. There were 45 ha of arable land, 5 ha of orchard and 300 ha of forest. Because it was such an extreme outlier, it was not considered in the calculation of average farm size, also because some parts were located outside the researched area.

The average farm size with the largest area (43.89 ha) was surveyed in the Šoštanj municipality (Table 6).

Table 6: *Surveyed municipalities and their agricultural characteristics.*

	Municipality			Total
	Velenje	Šoštanj	Šmartno ob Paki	
Number of researched farms	16	14	10	40
Agricultural land (ha)	253	614.58	101.7	969.28
Average farm size (ha)	15.81	43.89	10.17	24.23

(Source: Agriculture Census 2010 in SORS, 2013)

4.2 Agricultural managers by age and education attainment

We interviewed 40 farm owners and 92.5% provided their birth data. We wanted to determine how and whether the average age of farm owners would be reflected the actual state of agricultural holdings. The interviewed farm managers were on average 54.95 years old.

Organic farms are managed by younger owners (in average 3.64 years younger) than the conventional farms were, where the owners were 55.77 years old in average (Table 7). The youngest farm owner was 31 years old, whereas the youngest farmer who ran a conventional farm was 40 years old.

The oldest owner of an organic farm was 67 years old, and the oldest manager of a conventional farmer was 82. During the fieldwork survey, we established that additional administration needed for organic farming represented a kind of discouragement for organic farmers. The average age of a Slovene family farm manager was 57 in 2010 (Agriculture Census, 2010). The average age of Slovene farmers is probably also a reason that farmers and their products are hardly competitive on the agricultural market. New, younger farm managers are required. Our survey showed the 38% farms had no known successor.

If we consider average age of conventional/in conversion farm owners and the sex indicator, male owners are an average of 6.37 younger than female farm managers (59.25 years). The organic farm managers are less different by age and it was vice versa; men are 1.3 years older than women (Table 7).

Table 7: *Average age of the researched family farm managers.*

Farm type	conventional/in conversion			organic		
Sex	total	male	female	total	male	female
Average age	55.77	52.65	59.25	52.13	52.6	51.3

Regarding the education, the organic farms' managers were better educated; three managers had B. Sc. Degree, one was Ph. D., three had finished trade degrees and two had graduated from secondary school (Fig. 1).

Conventional farms and farms in conversion were run mainly by farmers with finished professional and secondary school degrees.

These differences proved that organic farming requires younger, well-educated managers with competences, skills, knowledge and courage for facing and coping with stringent environmental and other regulations relating more modern farming attitude. In comparison with the Slovene average, the majority (37.2 %, SORS, 2013) had basic school education.

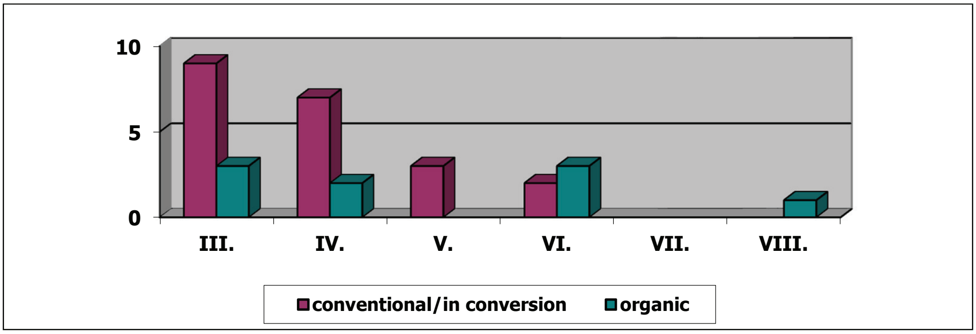

Figure 1: *Interviewed family farm managers by educational attainment.*

4.3 Family farms and renewable energy production

Our research found four organic farms and four conventional farms to be renewable energy producers, mostly with wood biomass. One integrated farm had its own electricity production from renewable sources. Using these data, we cannot conclude that the exploitation of renewable sources had any significant correlation with the farm orientation.

Although renewable energy production should be incorporated in sustainable farm management, most of the plants in the valley are owned by non-agricultural managers. There is one biogas plant (150 kW) and one small hydro power plant (35 kW) in the researched area. Solar plants are more common due to government subsidies, especially in recent years, because Slovenia has been following EU measures and is obliged to have a 25% share of renewable sources in final energy consumption by 2020.

Table 8: *Solar plants in number and by capacity (in kW) in Šalek Valley installed, 2009–2012.*

Municipality/Year	2009	2010	2011	2012	TOTAL
Šmartno ob Paki	0	2 (18)	1 (116)	3 (124.62)	6 (258.62)
Šoštanj	0	2 (98)	4 (847.05)	6 (442.91)	12 (1387.96)
Velenje	2 (19)	10 (633)	8 (249.06)	15 (1710.24)	35 (2611.3)
TOTAL	2 (19)	14 (749)	13 (1212.11)	24 (2277.77)	**53 (4257.9)**

(Source: Geographical Information system for RES, Sončne elektrarne v ..., 2013)

As a promising best practice case, renewable technologies or programs could play a significant role since they enable and are aimed to provide energy access to the poor in the "bottom of the pyramid" (BOP). Thus billions have been spent and will be spent on projects such as expensive line extensions or solar panels to the poor living in "last mile" communities (Santiago, Roxas, 2012). Renewables' exploitation also prove a sustainable and responsible community model, which corresponds not only with the poor at the BOP, their traditional responses to income and energy poverty.

According to Klagge and Brocke (2012), decentralized electricity generation from renewable sources can become an important factor for local economic development in rural regions and their urban centers. Another advantage of regarding the internal resources is that local (pioneer) firms take up the business challenges associated with renewable energies and are successful in entering not only local, but also national or even international markets. Decentralized electricity generation from renewable sources can develop a region very dynamically. Based on the early activities of some pioneers, such regions introduce very specific organizational structures and enter development paths in which renewable energies are an important economic factor. However, special supporting conditions and constellations are needed to enable that type of development, including representatives of utilities/grid operators, local politics and administration, civil society, plant operators and other businesses involved in the renewable energy value chain.

5 CONCLUSIONS

The fieldwork has revealed a small share of the farms engaged in organic food production. The main point of organic farming should be awareness for sustainable environmental management to maintain soil fertility, water sources and air quality when planning agriculture development. In addition, renewable energy production and energy self-supply should be incorporated.

There are still many agricultural holdings with the owner is older than average, where the successor is known, but the actual manager has still not transferred the property and management rights to the descendant who would introduce innovations and manage the farm development. We determined that 38% of interviewed farms have not resolved the succession issue.

The research discovered that on average organic farms are larger than conventional and integrated agricultural holdings. There are two extremely large organic farms: one 230 ha and another 350 ha with some areas out of the researched region. The last farm was too much of an outlier to be included in data analysis of average agricultural holdings' size.

Organic farms' managers were younger and better educated than conventional farms' owners. We assumed that more skills and competences are required for running an organic farm (to obtain the organic farm certification, to edit all the documentation for application and farming after gaining the certificate, etc.).

We cannot declare organic farming to be more energy efficient since the same number of conventional and organic farms used renewable sources for their own energy production.

It would be very significant to encourage agricultural holdings and their successors (the Agricultural Census data for 2010 showed that the manager of a Slovenian farm was on average 57 years old, finished primary school and had no formal agricultural education). The average farm owner in the surveyed area was three years younger in comparison to the Slovene average (2011 data). The transfer from conventional farming methods to organic farming would assure the direct sale of the organic food to consumers, since demand for healthy food has been increasing, and the food without any chemical treatment is more perishable. According to the Agricultural Institute of Slovenia data, the country is only 68–75% self-sufficient in food production.

We aim at 10% increase, which would reduce Slovenia's dependence on foreign food markets. However, first more incentives of Chamber of Agriculture and Forestry and the relevant ministries should persuade farmers to manage their agricultural holdings in a sustainable way.

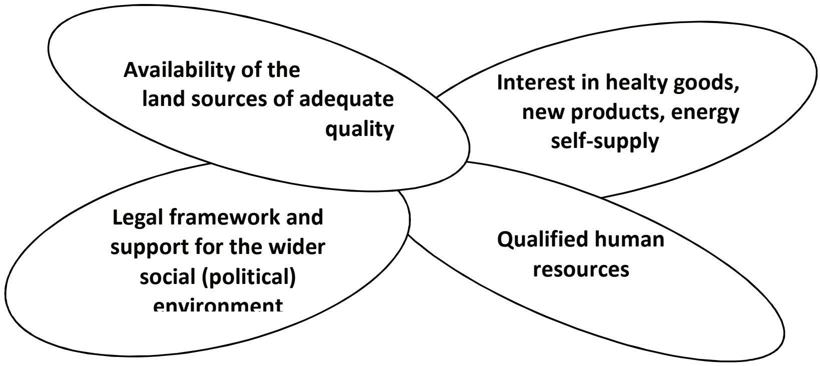

Figure 2: *Sustainable farming factors.*

Moreover, the main agricultural constraints (inefficiency and lack of competitiveness due to fragmentation and small farms, a large amount of hired land and the uncertainty caused by the global economic crisis) simply leads to the supplementary activities for Slovenian farmers. Renewable energy production is a highly appropriate supplement for organic farming and should be elementary in the sustainable agricultural management. Since it demands quite an investment and because was a high national priority recently to follow the EU commitments of the obligatory share of renewables, many solar plants were subsidized in the Šalek Valley. In 2012, there was more than half (53.5%) of total solar plants of the Šalek Valley were installed (total capacity from 2009–2012 amounted to 4.26 MW). Private investors were in the minority.

In 2009–2012, 53 solar plants were built with a capacity of 4.26 MW; in 2013, no solar plant was constructed due to the abolition of favorable conditions of construction. Recently (August 2014) farmers are no longer supposed to produce energy and have solar/hydro plant as a complementary activity. According the newly adopted legislation the possibility of electricity produced from all renewable energy sources was removed except from biomass, manure, slurry and vegetable substrate.

The action plan of European Commission until 2025 anticipates the sustainable growth and implementation of bio-economics, which means development of industries based on raw natural (biological) origin without fossil resources. It should be a promotion of a development guideline, which would connect different fields and activities, e.g. energy, chemistry, forestry with wood activity, agriculture etc. The case of agricultural activity should promote a sustainable farming with lower emissions, natural (renewable) sources stocks and biodiversity conservation.

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First year students of the Environmental Protection College (class of 2010–2011) introduced the fieldwork to the subject of Protection and Evaluation of the Geographical Environment. They carried out a survey on the diversity of the Šalek Valley rural area and its potential for sustainable farming. Later, the survey was an opportunity for student placement. With their fieldwork on the use of renewable sources, the 1st year postgraduate students (2012–2013) in the subject of Sustainable Planning of Landscape Resources did a great job.

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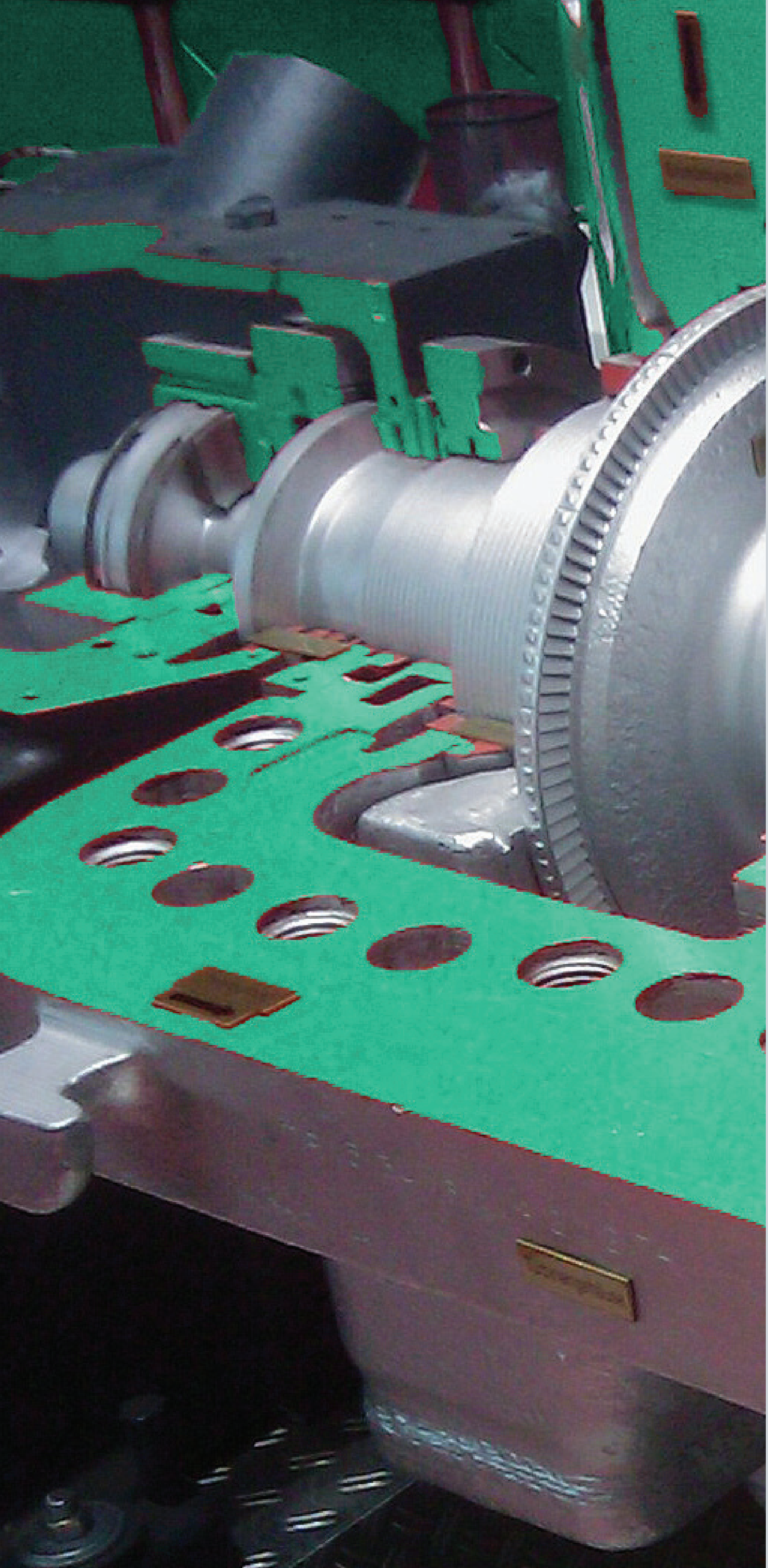

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