# Geothermal energy of Slovakia - $CO_2$ emissions reduction contribution potential (background study for conservative and non-conservative approach)

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*Total geothermal energy potential is estimated for 209 714 TJ per year or 6 650 $MW_{th}$. Natural conditions define a use of thermal waters for heat generation only. Accepting proportion of real achievable output of geothermal projects in the non-conservative scenario at a rate of 1 861 $MW_{th}$ or 13 440 TJ per year, yearly carbon dioxide savings are up to reach 0,357 $MtCO_2.yr^{-1}$ or 12,5 of cumulative $MtCO_2$ in 35 years. By a contrast, introduction of conservative approach points to increase in a geothermal heat production from 145 to 243 TJ per period or 6 944 TJ of cumulative 35 years production, with a real outcome of 0,45 $MtCO_2$ cumulative carbon dioxide savings, corresponding to yearly real savings from 9,4 .$10^{-3}$ to 15,8 .$10^{-3}$ $MtCO_2$.*

**Key words:** *carbon dioxide savings, fossil fuels savings, geothermal energy, savings calculation approach*

## Introduction

Increased public and scientific focus at anthropogenic greenhouse gasses emission contribution on disturbances in natural carbon cycle and global climate changes triggered debates, actions and policies for its mitigation on local or regional scale last decades, all led by the UNFCCC – the United Nations Framework Convention on Climate Change.

The Slovak Republic is a typical high-income advanced economy, considered a country of low AHS (atmosphere harmful substances) emissions but traditional fossil fuels oriented, with 6,7 % of a RES (renewable energy sources) share on the total primary energy mix - PEM (less than 20 % on power generation and app. 7 % on a heat production), however, various policies are still being introduced or already of force, e.g. Act. No. 309/2009 Coll. on the Promotion of Renewable Energy Sources and High Efficiency Cogeneration, or the EU/EC Conception of Utilization of Renewable Energy Sources, to meet the EU-set up targets for 2020 – a 14 % share of the RES on the primary energy mix. An estimated total energy potential of renewable energy sources (including hydropower) for the country reaches 6 180 GW (194 860 PJ), with 6 650 $MW_{th}$ for the geothermal energy (210 PJ) – proportionally 0,1 %, as indicated and calculated for 26 perspective geothermal localities. Hence temperature conditions, technical implementation possibilities and economics define use of identified hydrothermal sources for direct, heating and heat supply use only.

A focus of the paper is to present an idea, theoretical background for further detailed analysis and preliminary calculations to assess relative contribution of hydrothermal sources on TFF (traditional fossil fuels) heat production associated $CO_2$ emissions mitigation in a conservative and non-conservative approach, assuming a use of hydrothermal sources for space heating only.

## Background informations

### Geothermal energy – installed capacity worldwide and in Slovakia (an overview)

Global concern of geothermal energy utilization (installation, innovation) and research has grown intense last years, both for power and heat generation. The on-line electricity production rise up reaches 20 % as installed capacity increased from 8,93 $GW_e$ (2005) up to 10,71 $GW_e$ in 2010. Non-conservative approach expects (assuming planned projects to run) a power production at a rate of 18,5 $GW_e$ in 2015 [1], corresponding to 73 % growth over 2010 with 52 % increase in number of producing countries from 23 (2005) to 35 in 2015 [2]. Single-stand or cogeneration based direct utilization tends to rise up as well, as the installed capacity increased from 28,3 $GW_{th}$ in 2005 towards the 50,6 $GW_{th}$ in 2010, representing an increase of 79 %, hence 78 countries introduce the geothermal energy into their PEM [3, 4].

While there is no geothermal project operating for a power generation, the Slovak Republic is among first 30 countries worldwide in geothermal heat production and supply, with 163 $MW_{th}$ (equal to 2,5 % of the total geothermal potential of the country) installed at 82 sites, representing 1,5 % proportion on the global direct utilization [5]. The highest installed capacity concentrates in the Trnava County

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(45 $MW_{th}$ or 27,98 %), followed by the Nitra County (39 $MW_{th}$ or 24,2 %) and the Žilina County (32 $MW_{th}$ or 19,6 %) [6]. In the direct energy utilization mix, the highest installed capacity documented is 74 $MW_{th}$ (45,4 %) for recreational purposes and health services, ahead of greenhouse heating (17 $MW_{th}$ – 10,8 %), individual space heating (16 $MW_{th}$ – 10,2 %), fish farming (12 $MW_{th}$ – 7,3 %), geothermal district heating (11 $MW_{th}$ – 6,6 %) and others [7]. As observed for last years, implementation of geothermal heat pumps becomes more rapid, now at a level of 2 $MW_{th}$, equal to 1,2 % share on total installed capacity [8].

**Slovakia – geothermal sources**

Twenty six perspective geothermal localities are identified within the country (tab. 1, fig. 1), counted for 34 % of the whole territory, with a total thermal potential balanced for 6 650 $MW_{th}$, out of which natural sources represent 710 $MW_{th}$ (10,6 %) and 5 950 $MW_{th}$ (89,3 %) count for reserves [6]. Structures are mostly of low enthalpy (exceptions are documented for high depths at the northern and eastern part of a Danube Basin and the Eastern Slovakian Basin), liquid phase and basinal hydrothermal character.

Such a spatial occurrence resulted from geological structure and evolution of the Western Carpathians, and therefore combined impact of different organization of deep neotectonic blocks, irregular introduction of heat from the mantle, courses of major discontinuities, young Neogene volcanism, distribution of radioactive sources, thickness of the crust and hydrogeological conditions [9]. Inmonotonous heat flow and temperature distribution patterns correlate well each other, with a geothermic activity increased and high close to volcanic mountains or towards centers of Neogene basins, while relatively low activity is observed in most of Tertiary intramountain basins and core mountains. A monotonous geothermic field sets to the Flysch Belt [10].

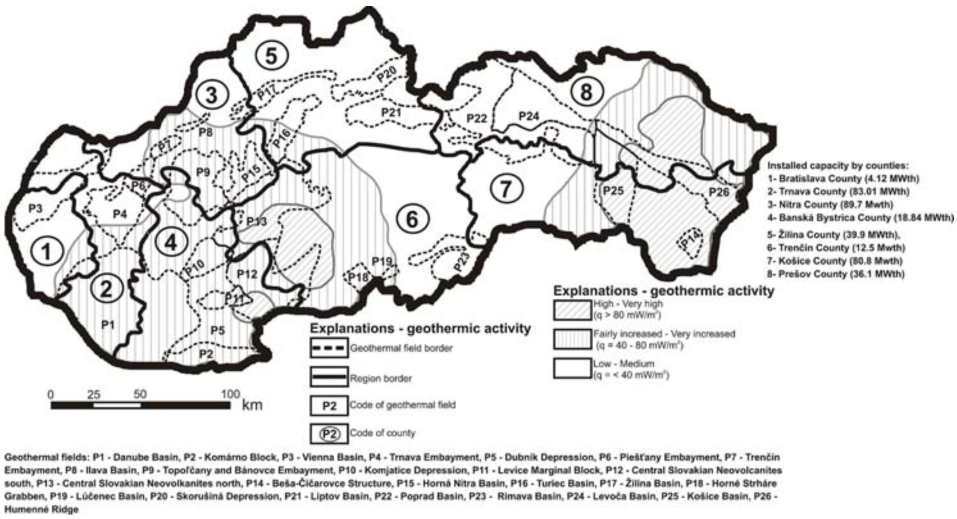


*Fig. 1. Perspective geothermal localities –geothermic activity and installed thermal capacity by county. Modified after: [5 – 10].*

*Tab. 1. Perspective geothermal localities by code – total thermal potential (TTP), possible renewing energy sources (PRES) and utilizable thermal potential ($PRES_u$). Modified after: [10, 11].*

| Code | TTP | PRES | $PRES_u$ | Code | TTP | PRES | $PRES_u$ |
|---|---|---|---|---|---|---|---|
| | [$MW_{th}$] | [$MW_{th}$] | [$MW_{th}$] | | [$MW_{th}$] | [$MW_{th}$] | [$MW_{th}$] |
| **P1** | 150 | 78 | 51 | **P14** | 268 | 139 | 91 |
| **P2** | 273 | 142 | 92 | **P15** | 20 | 10 | 7 |
| **P3** | 511 | 266 | 173 | **P16** | 23 | 12 | 8 |
| **P4, P6** | 44 | 23 | 15 | **P17** | 13 | 7 | 4 |
| **P5, P12** | 150 | 78 | 51 | **P19, P23** | 26 | 14 | 9 |
| **P13, P18** | | | | **P20** | 17 | 9 | 6 |
| **P7, P8** | 15 | 8 | 5 | **P21** | 35 | 18 | 12 |
| **P9** | 18 | 9 | 6 | **P22, P24** | 1316 | 684 | 445 |
| **P10** | 392 | 204 | 132 | **P25** | 1280 | 666 | 433 |
| **P11** | 126 | 66 | 43 | **P26** | 822 | 427 | 278 |

**Slovakia – primary energy mix (PEM) and heat production**

Even though there is a continuous progress in RES introduction for both, the power and the heat generation, the Slovak Republic is still, however, a traditional, fossil-fuels based economy. Proportionally, in a heat generation (fig. 2) counted for 43 050 TJ, a production from fossil fuels reached 87,6 % (37 710 TJ) while renewables shared 7 % (3 033 TJ), followed by cogenerated heat of nuclear based power generation rating 5,4 % (2 307 TJ) [12]. In the same period, total electricity produced in a country counted for 24 470 GWh, with a leading position of nuclear-based, sharing 51 % (14 080 GWh), followed with TFFs of 30 % proportion (8 180 GWh) and renewables 19 % (5 200 GWh), large hydro including [13].

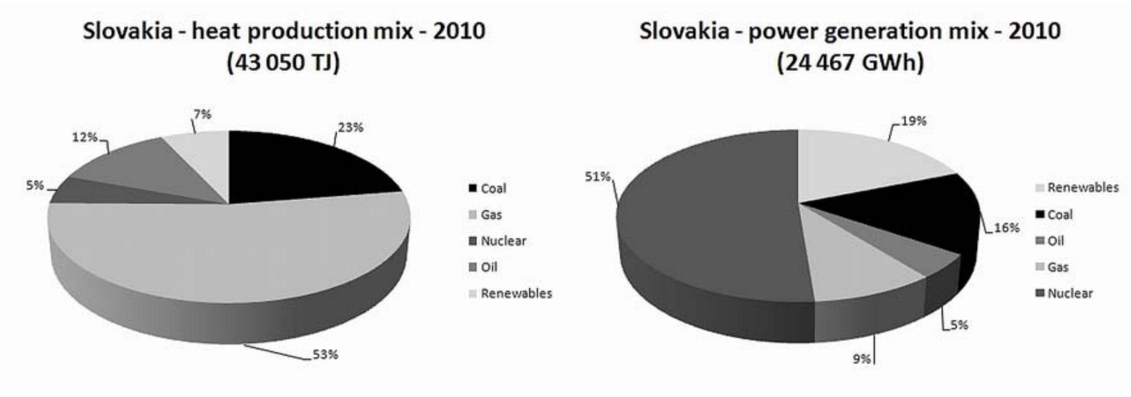


*Fig. 2. Slovakia – power and heat production energy mix. Modified after: [12, 13].*

## Methodology

In forthcoming analysis, a heat generation from nuclear and other than geothermal sources is neglected, with TFFs considered as coal, natural gas and oil (diesel).

A non-conservative approach presumes a maximum utilization of achievable geothermal sources, kept constant in time, relative to actual heat production and proportion of traditional fossil fuels to define savings potential as a positive scenario. A conservative approach respects actual situation in primary energy mix for a heat generation and social-economic factors of reasonable impact to yearly growth in heating demand and supply. For the fossil fuels and geothermal energy supply, a yearly increase rate of 2 % is preserved in observed period. Both, the conservative and non-conservative approaches, however, assume a unifying heat demand behavior of users, not varying in a year.

**Assumptions – traditional fossil fuels**

- heating values: coal: 11 $MJ.kg^{-1}$ [14], natural gas: 31 $MJ.m^{-3}$ [15], oil: 41 $MJ.m^{-3}$ [13],
- $CO_2$ emission factors: coal: 96 $t.TJ^{-1}$ [16], natural gas: 55 $t.TJ^{-1}$ [15], oil: 73 $t.TJ^{-1}$ [17],
- traditional fossil fuels heat production: kept constant in time (37 710 TJ),
- traditional fossil fuels proportion factor: actual from 2010 (fig. 2).

**Assumptions – geothermal sources**

- geothermal fluids $CO_2$ emission factor: 0,4 $t.TJ^{-1}$ [18],
- emission factor of fluids kept constant at 0.4 $t.TJ^{-1}$ [19],
- mean GDHS (geothermal district heating system) thermal efficiency: 38 % [20],
- GDHS lifetime: 35 years [21],
- heating period: 220 days 5280 hours.

**Calculations – utilization estimation and potential**

The total thermal potential (1) is a function of achievable discharge, reservoir temperature defined specific heat capacity, and reservoir to reference temperature difference [22]:

$$TTP = Q_{dis} \cdot c_{Tres} \cdot \left(T_{res} - T_{ref}\right) \quad (1)$$

where: TTP – total thermal potential [$MW_{th}$], $Q_{dis}$ – discharge [$kg.s^{-1}$], $c_{Tres}$ – specfic heat capacity of geothermal fluid at reservoir conditions [$J.kg^{-1}.K^{-1}$], $T_{res}$ – reservoir temperature [K], $T_{ref}$ - reference temperature generally considered as 15 °C or 288.15 K [23].

Hence a need of reservoir sustainable management, only possible naturally renewing energy sources (2) are up to be counted in geothermal projects planning, thus the TTP limits for the PRES as follows:

$$PRES = A.q.\left[\frac{(T_{wh} - T_{ref})}{(T_{res} - T_n)}\right] \quad (2)$$

where PRES – potentially renewing energy sources [$MW_{th}$], A – area [$m^2$], q – heat flow density [$W.m^{-2}$], $T_{wh}$ – borehole wellhead temperatre [K], $T_{ref}$ – reference temperature [K], $T_{res}$ – reservoir temperature [K], $T_n$ – neutral zone temperature [K].

In hydrogeological and geothermic conditions of the Western Carpathians, an approximation of 52 % for the PRES share on TTP is reasonable [23]. Moreover, a real installation capacity is limited by fairly increased purchasing capacity, economics, subsidiaries and a level of social stress adaptation to new implementations [24], thus the utilizable (substitution) potential – $PRES_u$ counts for 65 %.

With a $PRES_u$ assessed, number of heating days set as constant and known mean GDHS thermal efficiency, a real potential for a heat production is defined as follows (3):

$$Q_{gtp\_r} = PRES_u \, . \eta_{mean} \, . HD \quad (3)$$

where: $Q_{gtp\_r}$ – real heating potential / output [$MW_{th}.yr^{-1}$], $PRES_u$ – utilizable potential [$MW_{th}$], $\eta_{mean}$ – thermal efficiency [-], HD – heating days factor in hours per year [hrs].

**Calculations – $CO_2$ savings potential**

Submitted study understands the savings as a mitigation process involving a substitution of $CO_2$ emitting sources by non-emitting ones [25], thus emissions potentially saved in the same process of the same intensity. If there is fossil fuels – geothermal substitution ($Q_{gtp\_r}$) in a heat supply, the gross savings– $CO_{2sv\_gr}$ (4) are up to reflect the actual share of fossil fuels on the energy mix - $p_{PEMi}$ with their emission factor contributing – $EF_{TFFi}$:

$$CO_{2\,sv\_gr} = \sum_{i=1}^{n} \left( Q_{gtp\_r} \, . EF_{TFFi} \cdot p_{PEMi} \right) \quad (4)$$

where: $CO_{2sv\_gr}$ – gross $CO_2$ savings [$tCO_2.yr^{-1}$], $Q_{gtp\_r}$ – real heating potential [$TJ.yr^{-1}$], $EF_{TFFi}$ – emission factor of traditional fossil fuels [$tCO_2.TJ^{-1}$], $p_{PEMi}$ – fossil fuel proportion on primary energy mix [-].

Additionally, unexpected leaks, utilization process and post-use thermal fluids spill define then a need to assess geothermal fluids related carbon dioxide production- $CO_{2gtf\_prod}$ according to the emission factor in a heat generation process $EF_{gtf}$ (5):

$$CO_{2\,gtp\_prod} = Q_{gtp\_r} \, . EF_{gtf} \quad (5)$$

where: $CO_{2gtp\_prod}$ – $CO_2$ production from geothermal source [$tCO_2.yr^{-1}$], $EF_{gtf}$ – emission factor of geothermal source [$tCO_2.TJ^{-1}$], $Q_{gtp\_r}$ – real heating potential [$TJ.yr^{-1}$].

Real carbon dioxide savings – $CO_{2sv\_r}$ (6) result then from a subtraction of $CO_2$ produced by geothermal source out from gross savings defined:

$$CO_{2\,sv\_r} = CO_{2\,sv\_gr} - CO_{2\,gtp\_prod} \quad (6)$$

where: $CO_{2sv\_r}$ – real $CO_2$ savings [$tCO_2.yr^{-1}$], $CO_{2sv\_gr}$ – gross $CO_2$ savings [$tCO_2.yr^{-1}$], $CO_{2gtp\_prod}$ – carbon dioxide production from geothermal source [$tCO_2.yr^{-1}$]

**Calculations – fossil fuels savings**

Among a potential of carbon dioxide saved within a mitigation process, environmental studies use to review real reduction (savings) in fossil fuels consumption ($m_{TFF\_sv}$) to provide complex situation and socio-economical benefits of RES implementation. Analysis based on integration of RES – based project then considers a real heat production by RES ($Q_{gtp\_r}$) capable to govern a heat production from the fossil fuels according to their partial heating values (LHVi), proportion on the primary energy mix (PEMi) and heat production efficiency ($\eta_{th}$) within a process (7)

$$m_{TFF\_sv} = \sum_{i=1}^{n} \left[ \frac{(Q_{gtp\_r} \cdot p_{PEMi})}{(\eta_{th} \, . LHV_{TFFi})} \right] \quad (7)$$

where: $m_{TFF\_sv}$ – fossil fuels savings [t.yr$^{-1}$], $\eta_{th}$ – thermal efficiency of heat generation process[-], $LHV_{TFFi}$ – low heating value of TFF [t.TJ$^{-1}$ or m$^3$.TJ$^{-1}$], $Q_{gtp\_r}$ real heating potential [TJ.yr$^{-1}$], $p_{PEMi}$ – fossil fuel proportion on primary energy mix [-].

## Results – non conservative approach (NCA)

### Geothermal heat utilization / production

The NCA, positive in expectation of utilizing the achievable geothermal potential for space heating purposes, relies on TTP known [10, 11] and PRES calculated due to 52 % assumption [23] - required for the $PRES_u$ definition in a basis. Then, with a summarized $PRES_u$ for all geothermal fields set (app .65 % of the PRES), mean thermal efficiency of heat generation process defined at 38 % and 5 820 heating hours in a year instated into (3), resulting 3 733 $GWh_{th}$ or 13 440 TJ represent a heat potentially generated in a year. If a mean lifetime of geothermal heating projects is 35 years, the final heat generation in a steady-state operation run may head to 470 400 TJ at the end of the period.

### Carbon dioxide savings

Substituting the yearly real heating output of geothermal sources (13 440 TJ per year), various emission factors of fossil fuels and their proportion of heat production primary energy mix into (4), resulting gross carbon dioxide savings are then up to reach 0,363 $MtCO_2$.yr$^{-1}$. The bulk summarizes partial savings from coal (0,087 $MtCO_2$.yr$^{-1}$), natural gas (0,266 $MtCO_2$.yr$^{-1}$) and oil (0,01$MtCO_2$.yr$^{-1}$) as a consequence of their substitution with a geothermal sources, proportionally relative to their actual PEM on a heat generation. Analogously, in case of 35 years long period during which the substitution is expected to run, savings calculated at the end then represent cumulative gross amount of carbon dioxide saved at a rate of 12,7 $MtCO_2$. A need to subtract geothermal derived $CO_2$ production (5) at 5,3.10$^{-3}$ $MtCO_2$.yr$^{-1}$ or 0,21 $MtCO_2$ of cumulative production after 35 years consequently comes out from geothermal fluids utilization and post-use treatment. The fact the $CO_2$ is produced by a geothermal source reduces then gross savings into real carbon dioxide savings (6) from yearly 0,363 $MtCO_2$.yr$^{-1}$ down to 0,357 $MtCO_2$.yr$^{-1}$, representing cumulative 12,5 $MtCO_2$ savings at the end of considered lifetme interval. Hence geothermal heat production and carbon dioxide savings at yearly rate are kept constant within NCA in time, the increase in cumulative savings per year is to behave linearly (fig. 3).

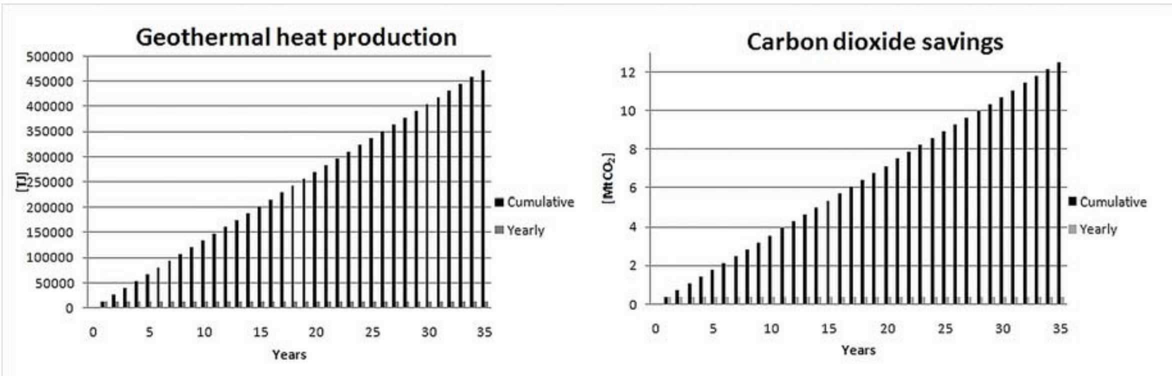


*Fig. 3. The non-conservative approach (NCA): geothermal heat production (left) and real carbon dioxide savings (right).*

### Fossil fuels savings

Recent heat production based on fossil fuels reaches 37 710 TJ.yr$^{-1}$. Implementation of geothermal heating into PEM scheme at yearly 13 440 TJ leads towards traditional sources consumption reduction, due to actual PEM proportion. The rate, at which fossil fuels are saved (7) consequently relates to geothermal heat production intensity ($Q_{gtp\_r} \approx$ 13 440 TJ.yr$^{-1}$), PEM proportion for fossil fuels (coal – 26 %, natural gas – 60 %, oil 14 %), heat production mean thermal efficiency ($\eta_{th} \approx$ 35 %) and low heating values ($LHV_{coal}$ – 11 MJ.kg$^{-1}$, $LHV_{ng}$ – 31 MJ.m$^{-3}$, $LHV_{oil}$ – 41 MJ.m$^{-3}$).

Following the NCA approach (tab. 2), yearly coal savings may reach 0,87 Mt out from app. 2,51 Mt consumed per year in current energetic situation for heat generation, representing 34 % savings rate. Constant savings trend then shows a potential to save 30,45 Mt of coal after 35 years. A bulk of natural gas saved in scenario may rise up to 749,2 .10$^6$ m$^3$ per year (36 % savings of current consumption) or 26,22 .10$^9$ m$^3$ as cumulative. Oil savings are up to reach 201,6 10$^6$ m$^3$ every year (51 % savings rate to actual consumption) or 7,05 .10$^9$ m$^3$ as cumulative.

*Tab. 2. The non-conservative approach: fossil fuels consumption over savings comparison.*

| TFFS | Consumption | Savings | |
|---|---|---|---|
| | Current $Q_{TFF\_sup}$ | Yearly | Cumulative |
| **Coal** | 2,51 $Mt.yr^{-1}$ | 0,87 $Mt.yr^{-1}$ | 30,45 Mt |
| **Natural gas** | 2091 $.10^6\ m^3.yr^{-1}$ | 749,2 $.10^6\ m^3.yr^{-1}$ | 26,2 $.10^9\ m^3$ |
| **Oil** | 371 $.10^6\ m^3.yr^{-1}$ | 201,6 $.10^6\ m^3.yr^{-1}$ | 7,05 $.10^9\ m^3$ |

## Results – conservative approach (CSA)

Alike NCA, the conservative approach (CSA) relates to renewable energy marked and socio-economic-technical possibilities and purchasing situation in the country [26] – in case of Slovakia, the current geothermal heat production is 145 TJ per year. A steady state (realistic) principle [27] of the approach then kept default trend in introduction of the source into primary energy mix constant in time. For Slovakia, last three years expressed 2 % yearly growth rate, justified to be maintained over observed period of 35 years as real due to economics and general support for RES introduction and promotion.

### Geothermal heat utilization / production

Accepting actual use of geothermal sources evaluated in 2010 for 145 TJ or 40,24 $GWh_{th}$ [5] and 2 % yearly increase rate, the cumulative geothermal heat produced over a period of 35 years may count for 6 944 TJ or 1 298 $GWh_{th}$. The production results from geothermal heat production growth from recent 145 TJ to 243 TJ (fig. 4) at the end of a period, representing 59 % total growth rate – actually reasonable in local conditions. With such weak subsidies for geothermal sources and generally high investment costs of geothermal projects, there is no sign of faster geothermal development in Slovakia.

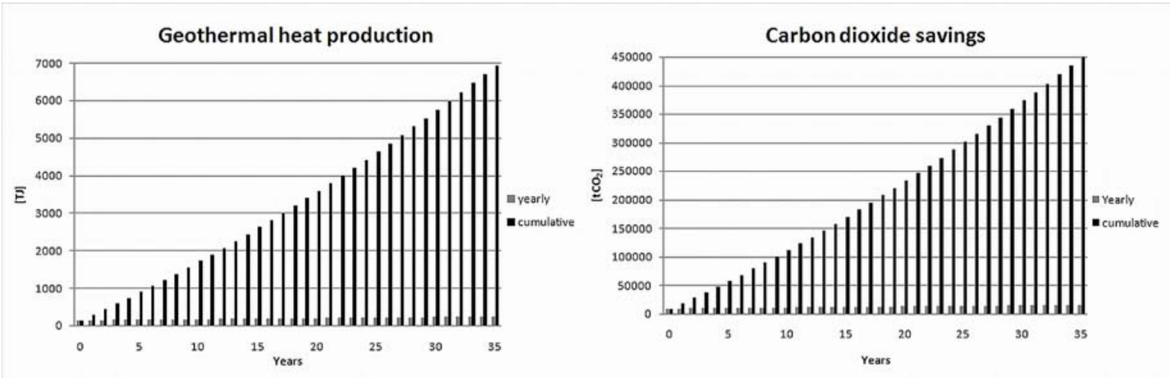


*Fig. 4. The conservative approach (CSA): geothermal heat production (left) and real carbon dioxide savings (right).*

### Carbon dioxide savings

Within the CSA analysis, the geothermal heat production ($Q_{gtp\_r}$) is a substitution variable factor in time, thus the intensity is not linear anymore but of growth character. This results in gross $CO_2$ savings (4) variation from current 9,46 $.10^{-3}$ $MtCO_2.yr^{-1}$ to 15,89 $.10^{-3}$ $MtCO_2.yr^{-1}$. Summarizing, cumulative gross carbon dioxide savings reach then 0,453 $MtCO_2$. As there is a need to subtract geothermal fluids produced $CO_2$ (5) during the drilling, installation, use and post-use campaign, evaluated for 57,6 $.10^{-6}$ $MtCO_2.yr^{-1}$ – 97,4 $.10^{-6}$ $MtCO_2.yr^{-1}$ (cumulative production is then 2,7 $.10^{-3}$ $MtCO_2$), yearly real carbon dioxide savings from the country inventory reach 9,3 $.10^{-3}$ $MtCO_2.yr^{-1}$ (current) to 15,8 $.10^{-3}$ $MtCO_2.yr^{-1}$ or 0,45 $MtCO_2$ mitigated as cumulative at the end of geothermal projects assumed lifetime period.

### Fossil fuels savings

Realistic scenarios for the conservative approach keep proportion factors of fossil fuels constant in time, but the heat demand to be covered varies over the observation period – hereby in the study the 2 % growth rate is expected. If current fossil fuels related heat production basis is accepted as 37 710 TJ per year, maintaining the growth rate results in 73 937 TJ of heat supplied after 35 years. Then, fossil fuels savings calculations (7) are up to reflect increase in TFF consumption to geothermal installation growth.

After substitution into (7), current coal savings may count for 9,29 $.10^{-3}$ Mt, however, this is up to increase to 15,5 $.10^{-3}$ Mt. Considering cumulative savings, the amount of coal saved from combustion processes may reach 0,444 Mt. For a natural gas, current savings of 13,91 $.10^6$ $m^3$ move towards 25,03 $.10^6\ m^3$ at the end of planned 35 years. This represents 684,69 $.10^6$ $m^3$ of total natural gas saved as cumulative after 35 years. Real savings in oil consumption vary from 4,94 .$10^6$ $m^3$ to 9,29 .$10^6$ $m^3$ during the timeline, resulting in 250,64 .$10^6$ $m^3$ of fuel cumulatively saved (tab. 3).

*Tab. 3. The conservative scenario: fossil fuels consumption over savings rate comparison.*

| TFFs | Consumption | | Savings | | |
|---|---|---|---|---|---|
| | **Current** | **After 35 yrs** | **Current** | **After 35 yrs** | **Cumulative** |
| **Coal** [Mt] | 2,51 | 4,93 | 9,29 .$10^{-3}$ | 15,5 .$10^{-3}$ | 0,445 |
| **Natural gas** [$m^3$] | 2091 .$10^6$ | 4100 .$10^6$ | 13,91 .$10^6$ | 25,03 .$10^6$ | 684,7 .$10^6$ |
| **Oil** [$m^3$] | 371,4 .$10^6$ | 728,3.$10^6$ | 4,94 .$10^6$ | 9,29 .$10^6$ | 250,6 .$10^6$ |

## Discussion and adds

### NCA / CSA comparison

Two different philosophies are compared in the study. While the non-conservative approach expects maximum utilization of achievable geothermal sources and the intensity is kept constant over an observed period, as well as the fossil fuels combustion is (steady state scenario), the conservative approach with its realistic scenario analyzed reflects time dependent growth rate of geothermal heating systems implementation and fossil fuels.

Resulting from philosophy comparison, the NCA derived savings may be understood as total potential of geothermal sources for carbon dioxide mitigation, while savings calculated according to CSA then represent a real potential that the country is capable to save in current social-economic-technical and natural conditions. Consequently, as it is typical for environmental studies, the CSA nears the real future development.

Accepting set principles, following table 4, if the CSA is up to represent real scenario and energy development, thus yearly 2 % increase rate in geothermal heat supply is sustained during 35 years, the cumulative geothermal heat production (6 944 TJ) is up to reach 1,48 % of energy potentially achievable l to be implemented (470 400 TJ). In carbon dioxide savings, current settings and scenario forecast the geothermal energy projects to mitigate cumulative 0,45 $MtCO_2$, representing 3,6 % of the itinerary geothermal sources are capable to reduce (a ratio of real CSA over real NCA savings).

*Tab. 4. NCA / CSA cumulative carbon dioxide savings and geothermal heat supply (production) comparison.*

| APPROACH | Cumulative real $CO_2$ savings [Mt] | Cumulative GT heat supply [TJ] |
|---|---|---|
| **Conservative** | 0,45 | 6 944 |
| **Non-conservative** | 12,50 | 470 400 |

Analogously in fossil fuels savings, the basis is represented by a bulk potentially saved according to NCA, while amount of fuels saved within CSA represent real capability of the country utilizing geothermal sources due to realistic forecast. Nominally (tab. 5), forecasted future development and implementation are up to contribute by 0,45 Mt of coal (1,5 %), 684,7 .$10^6$ $m^3$ of natural gas (2,6 %) and 250,6 .$10^6$ $m^3$ of oil (3,5 %) on fossil fuels consumption reduction.

*Tab. 4. NCA / CSA cumulative fossil fuels savings comparison.*

| TFFs | Cumulative savings | |
|---|---|---|
| | **Non-conservative** | **Conservative** |
| **Coal** [Mt] | 30,45 | 0,445 |
| **Natural gas** [$m^3$] | 26,2 . $10^9$ | 684 .$10^6$ |
| **Oil** [$m^3$] | 7,05 .$10^9$ | 250 .$10^6$ |

### Limitations

Authors claim the submission is a background study, a back-up for detailed analysis still in evaluation process within an "OPVaV-2008/2.2/01-SORO" project, therefore presented results relate to set up assumptions. A basic idea is then to create an integrated general background databasis and to provide a bulk overview to the problem.

Real impact of limitations is a function of approximations defined in assumptions. Unifying limitations come out from stabile emission factors of fossil fuels (even they may seasonally vary), expectations of constant and similar heating demand behavior for the country and a mean emission factor of geothermal fluids being utilized.

In non-conservative approach, the study expects maximum heat output from achievable sources and keeps current heat production from fossil fuels constant in time. It is doubtable whether the country will reach a geothermal heat production for space heating purposes at such a rate. The conservative approach, however, respects constant 2 % yearly growth rate for heat production from both, fossil fuels consumption and geothermal projects installation, however, both may vary in time reflecting international and local energetical, economical, technical, social and political situation. Described uncertainties then favor use of that realistic philosophy in further analyzes as it heads more towards reality.

**Oncoming research goals**

Following aim of the research is to assess a real impact of variables: various thermal fluids chemistry for emission factor definition, installation capacity, time-variable fossil fuels emission factors and social-economic agents, in combination with variations of primary energy mix, forced or expected.

**Summary**

Submitted paper manifests a background study for carbon dioxide emissions mitigation potential and fossil fuels combustion capability of geothermal sources associated with the Slovak Republic, both in non-conservative and conservative approach. Understanding the philosophy, while the non-conservative approach based results represent theoretical (or total) mitigation potential of geothermal sources in savings, conservative approach derived results reflect real capability of country for carbon dioxide mitigation and fossil fuels combustion reduction utilizing geothermal sources at realistic conditions.

As the Slovak Republic is traditional fossil fuels based economy, fossil fuels contribute 87,6 % (37 710 TJ) on the heat production within a primary energy mix, whereas geothermal heat production reaches 145 TJ, equal to 0,3 % proportion. By a contrast, total geothermal energy potential estimated counts for 209 700 TJ. A call for reservoir sustainability and combination of various external (socio-economic, technical) and natural parameters limits the total energy achievable for 13 440 TJ – a bulk potentially utilizable.

The non-conservative approach, calculating the real installation capacity at total rate shown potential to introduce 13 440 TJ per year of geothermal heat production into primary energy mix in ideal conditions to provide cumulative 470 400 TJ after 35 years – a period set up for analysis. Such an introduction is capable to mitigate 0,357 $MtCO_2$ per year or 12,5 $MtCO_2$ as cumulative. Consequently, fossil fuels savings resulting from scoped substitution may reach 30,45 Mt of coal, 26,2 $.10^9$ $m^3$ of natural gas and 7,05 $.10^9$ $m^3$ of oil possibly saved cumulatively.

If the conservative approach is accepted, calculations consider 2 % yearly growth rate in heat demand and geothermal heating projects installation. According to that, real geothermal heat production then rises from current 145 TJ to 243 TJ per year, resulting in 6 944 TJ of cumulative after 35 years. Constant geothermal projects installation then leads to 0,45 $MtCO_2$ cumulatively mitigated, as yearly real savings function input factors in time, thus vary 9,46 $.10^{-3}$ $MtCO_2.yr^{-1}$ to 15,89 $.10^{-3}$ $MtCO_2.yr^{-1}$. Analogously to the non-conservative approach, geothermal implementation into primary energy mix at defined rate per year is up to govern 0,445 Mt of coal, 684,69 $.10^6$ $m^3$ of natural gas and 250,64 $.10^6$ $m^3$ of oil cumulatively saved from the itinerary.

Recent situation on renewable energy market, purchasing capacity of the country, external social and economical parameters, all conjoint with natural conditions and technical limitations favor, however, the conservative approach (or realistic scenario) to move closer towards future development.

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**References**

[1] Holm, A., Blodgett, L., Jennejohn, D., Gawell, K.: Geothermal energy: international market update. *Geothermal Energy Association, 2010.*

[2] Bertani, R.: Geothermal Power Generation in the World 2005 – 2010 *Update Record. In: Proceedings World Geothermal Congress 2010, Bali, Indonesia, 25 – 29 April 2010. Geothermal Energy Association*.

[3] Lund, J.W.: Direct Heat Utilization of Geothermal Sources Worldwide 2005. *In: Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24 – 29 April 2005. Geothermal Energy Association*.

[4] Lund, J.W., Freeston, D.H., Boyd, T.L: Direct Utilization of Geothermal Energy 2010 Worldwide Review. *In: Proceedings World Geothermal Congress 2010, Bali, Indonesia, 25 – 29 April 2010. Geothermal Energy Association*.

[5] Fendek, M., Fendeková, M.: Country update of the Slovak Republic. *In: Proceedings World Geothermal Congress 2010, Bali, Indonesia, 25 – 29 April 2010. Geothermal Energy Association*.

[6] Fendek, M., Bágelová, A., Fendeková, M.: Geothermal energy worldwide and in Slovakia. *Podzemná voda, XVII (1), pp. 74 – 83, 2011*.

[7] Lund, J.W: Direct Utilization of Geothermal Energy. *Energies, 2010 (3), pp. 1443 – 1471.*

[8] Tometz, L., Dugáček, D.:. The potential of the Slovakian ground-waters as sources of renewable energy. *Acta Montanistica Slovaca, 15 – Special Issue (2), pp. 116 – 125, 2010*.

[9] Fendek, M., Remšík, A., Král, M.: The nature of geothermal resources in Slovak republic. *Slovak geological magazine, 5 (1-2), pp. 121 – 130, 1999.*

[10] Fendek, M., Remšík, A., Král, M.:Geothermal energy of Slovakia. *Slovak geological magazine, 5 (1-95), pp. 59-64, 2000*.

[11] Franko, O., Remšík, A., Fendek, M. eds: Atlas of geothermal energy of the Slovak Republic. *Slovak Geological Survey, Bratislava, 1995*.

[12] International Energy Agency, 2010. International Energy Outlook 2010. *U.S. Office of Integrated Analysis and Forecasting*.

[13] International Energy Agency, 2010. *Key World Energy Statistics. IEA Publishing house.*

[14] Fazekaš, J., Hantabál, E., Lauková, I., Puťoš, T., Zamboy, S., *1994. Záverečná správa s výpočtom zásob – výhradné ložisko Handlová – dobývací priestor Baňa Cígeľ. [manusctipt – final report] Hornonitrianske Bane, š.p., Prievidza. Geofond Bratislava*.

[15] SPP Distribucia a.s.: Hodnoty vážených priemerov kvantitatívnych parametrov zemného plynu. *SPP Distribúcia a.s., 2011*.

[16] International Panel On Climate Change, *2006. IPCC Guideline for National Greenhouse gasses inventories. International Panel On Climate Change.*

[17] Fridleifsson, I.B., Bertani, R., Lund, J.W., Rybach, L.: The possible role and contribution of geothermal energy to the mitigation of climate change. *In: IPCC Scoping meeting on Renewable Energy Sources Proceedings, Luebeck – Germany, 20 – 25 January 2008. International Panel On Climate Change*.

[18] Gunnlaugsson, E.: $CO_2$ savings by using geothermal energy for house heating in Iceland. *In: Workshop for Decision Makers on Direct Use of Geothermal Resources in Asia Proceedings, Tianjin, China, May 11 – 18 2008. Geothermal Energy Association.*

[19] [19] Remšík, A.: Nové poznatky z výskumu geotermálnej energie na Slovensku. *Enviromagazín, 2008 (6), pp. 7 – 9.*

[20] Ozgener, L., Hepbasli, A., Dicner, I., Rosen, A.: Exergoeconomic modeling of geothermal district heating system for building applications. *In: Ninth International IBPSA Conference, Montreal, Canada, August 15 – 18. 2005. IBPSA*.

[21] Ozgener, L., Hepbasli, A., Dincer, I.:. A key review on performance improvement aspects of geothermal district heating systems and applications. *Renewable and Sustainable Energy Reviews, 2007 (11), pp. 1675 – 1697.*

[22] Remšík, A., Fendek, M., Mello, J., Král, M., Bodiš, D., Michalko, J., Maďar, D., Vika, K.: Liptovská kotlina – regionálne hydrogeotermálne zhodnotenie. *[manuscript – final report] Ministry of the Environment of the Slovak Republic. Geofond Bratislava, 1998.*

[23] Fričovský, B.: Description and theoretical utilization suitability study of western and central hydrogeothermal structures associated with the Liptov Basin, Slovak Republic. *The History and current state of exploitation of mineral deposits in Eastern Slovakia conference proceedings, Prešov – Solivar, Slovakia, 30 – 31 March 2011. Slovak Technical Museum.*

[24] Mládek, J.: Industry and green energy potential adaptability of the Slovak Republic. *Enviromagazín (6/2005), pp. 23 – 27.*

[25] Fernandez, CH., Kulkarni, K., Polgar, S., Schneider, M., Webster, S.S.: Greenhouse Gas Mitigation Planning: A Guide for Small Municipal Utilities. *Donald Bren School of Environmental Science and Management – University of California at Santa Barbara, 2005*.

[26] Ferrao, P., Pacca, S.: Life-cycle assessment & Energy efficiency analysis. RES 604. RES | The School for Renewable Energy Science, *Akureyri, Iceland, unpublished, 2009*.

[27] Pacca, S.: Life-Cycle Assessment (LCA) as a Management Tool: An Emphasis on Electricity Generation, Global Climate Change, and Sustainability. Eco-Efficiency in Industry and Science, *23 (III), pp. 247 – 261, 2009*.