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GEOLOGICAL STORAGE OF CARBON DIOXIDE EMISSIONS: ENERGY CONSUMPTION MODEL FOR INJECTION PHASE

OGLEKĻA DIOKSĪDA EMISIJU ĢEOLOĢISKĀ UZGLABĀŠANA: ENERĢIJAS PATĒRIŅA MODELIS IESŪKNĒŠANAS POSMAM

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Introduction

Global warming and CO_2 concentration in the atmosphere have hastened research and development of new carbon free energy production technologies. One of the most progressive technologies to reduce CO_2 emissions in the atmosphere is the CO_2 sequestration process: capture and underground storage of CO_2 emissions produced by energy and manufacturing sectors. Despite the benefits, CO_2 capture and sequestration consumes additional energy, and thus lowering the total energy efficiency of this complex technological approach is important. This analysis is aimed to identify the overall efficiency of the CO_2 compression-injection phase and its implication to climate change mitigation.

Objective

The purpose of this analysis was to investigate the energy consumption required for the implementation of CO_2 sequestering from the compression phase to the injection phase including, and in comparison with, the CO_2 potential saved up by using sequestration technology. This analysis is the initial step in the life-cycle analysis of the CO_2 compression- injection processes. The CO_2 emissions generated by the transportation of CO_2 by pipelines are not covered in this paper.

Methods

The research is theoretically divided into several parts:

1. Analysis of CO_2 emissions generated by a reference power plant. The reference power plant is a 400 MW plant with electricity production of 2400000 MWh annually. Two scenarios were examined - combined cycle gas turbine technology and pulverized coal fired technology.
2. Calculation of energy required for CO_2 compression after capture and energy for CO_2 injection into a reference geological trap. As mentioned above, the research does not include the CO_2 transportation (incl. booster stations) phase from the compressors at the plant to the geological injection site.
3. Analysis of the results and conclusions.

For the purpose of this research, it is assumed that the compressed CO_2 is injected into the geological formation in the north-western part of Latvia named *Snēpele*. The calculations of the pump and compressor power requirements were performed in accordance with the McCollumm and Ogolen methodology [2]. The general scheme of the calculation algorithm is shown in Figure 1.

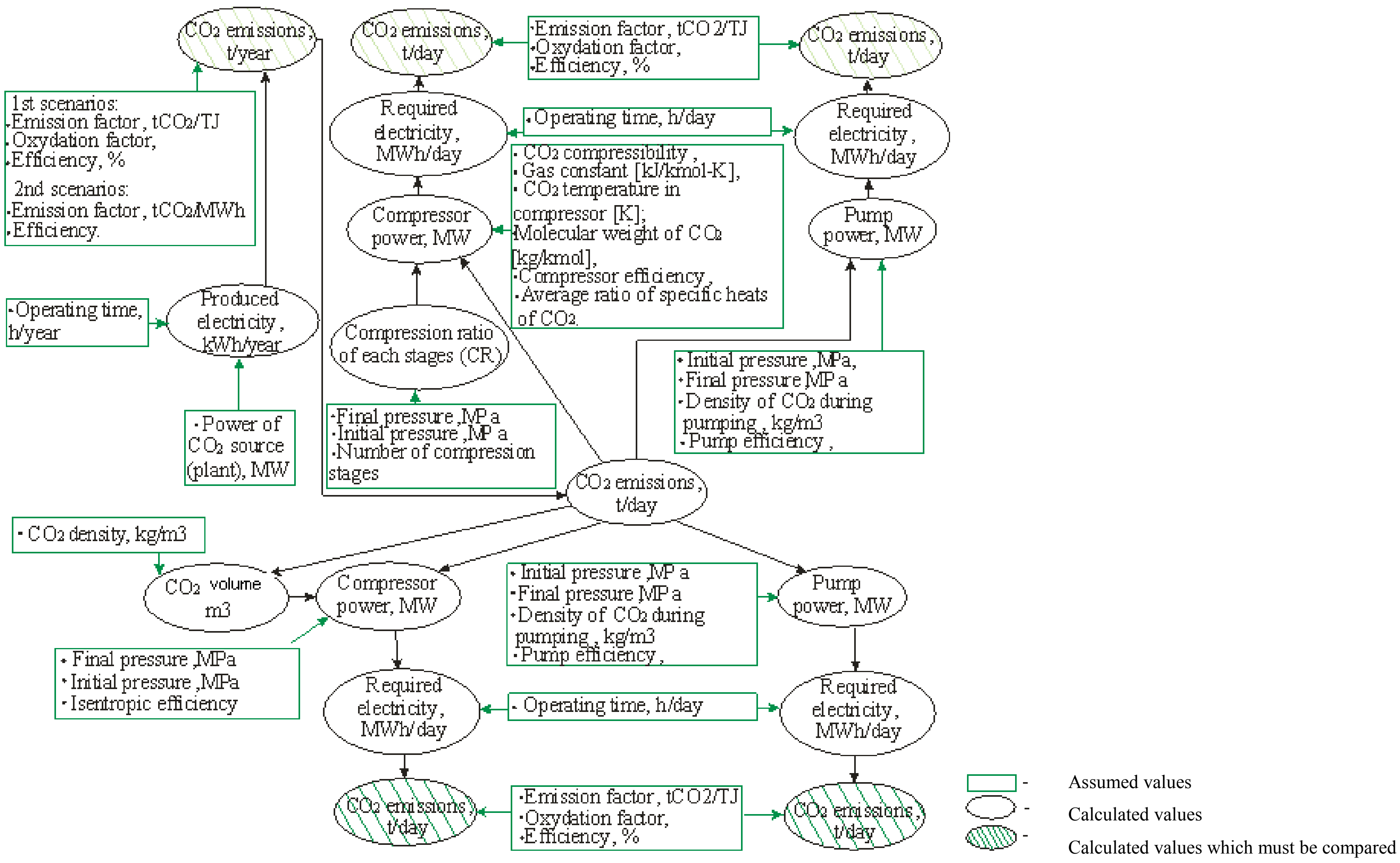

Figure 1. Data collection and screening algorithm

The estimation processes begins with the calculation of CO_2 emissions produced from (1) the gas power plant and (2) the pulverized coal power plant. The amount of CO_2 emissions were calculated in accordance with the methodology used in the *Latvian National Allocation Plan for* CO_2 *Allowances for 2005-2007*:

$$CO_2 = EQ_{kd} = \frac{N_{el} \times T \times R}{\eta} \qquad (1)$$

$N\ el$ – installed electrical capacity, MWel;
T - operating time, h/year;
R – emission factor, t CO_2/MWh;
η - efficiency of the plant.

The total amount of CO_2 emissions for the gas plant is equal to 964 561 t/year and for the coal plant - 1 991 485 t/year. For further calculations these numbers are modified to the amount of emissions produced per CO_2 injection system operating day, i.e. 20 hours/day.
When CO_2 is captured from the flue gases, it should be compressed from the atmospheric pressure to the pressure applicable for CO_2 transportation via the pipelines. Therefore, the amount of energy consumed by the compressor system must be evaluated as a potential impact to the environment through the compression power requirements:

$$W_{s,1} = \left(\frac{100}{24 \times 3600}\right)\left(\frac{mZ_s RT_{in}}{M\eta_{is}}\right)\left(\frac{k_s}{k_s - 1}\right)\left[(CR)^{\frac{k_s}{k_s - 1}} - 1\right] \qquad (2)$$

$W_{s,1}$ – compression power requirements for each stage, kW;
m - CO_2 mass flow to be injected in the geological formation, t/day;
Z_s - CO_2 compressibility for each stage;
R – gas constant, kJ/kmol*K;
T_{in} - CO_2 temperature at compressor inlet zone, K;
M - CO_2 molecular weight, kg/kmol;
η_{is} - efficiency of compressor;
k_s - average ratio of specific heats of CO_2 for each individual stage.

It is assumed that eligible number of compression stages is five.

To calculate the pumping power requirements the following formula is used:

$$W_p = \left(\frac{1000 \times 10}{24 \times 36}\right)\left[\frac{m\left(P_{final} - P_{cut-off}\right)}{\rho\eta_p}\right] \qquad (3)$$

W_p – pumping power, kW;
m – CO_2 mass flow, t/day;
ρ – CO_2 density for pumping time, kg/m^3;
η_p – efficiency of pump;
P_{final} – pressure of CO_2 transport via pipelines, MPa;
$P_{cut-off}$ – pressure at which the compressor switches to pumping, MPa.

The CO_2 power requirements for the pumping (injection) process mostly depend on the CO_2 flow and injection site geological properties and are integrated into thee calculation of the number of CO_2 injection wells. The geological properties significant for such calculation are pressure, temperature in the reservoir, permeability, thickness, depth, mobility and infectivity of CO_2 in the reservoir. The formula used for the calculation of the number of injection wells is the following:

$$N_{calc} = m / Q_{CO_2/well} \qquad (4)$$

N_{calc} - number of injection wells;
m- CO_2 mass flow to be injected in the geological formation, t/day;
$Q_{CO2/well}$ - CO_2 injection rate per well, t/day/well;
$Q_{CO2/well}$ = f (CO_2 injectivity, CO_2 mobility, permeability of reservoir, reservoir pressure, temperature, depth, thickness).

The general results on energy consumption requirements needed for CO_2 compression and injection phases are shown in Table 1.

Table 1.

Energy consumption for CO_2 compression and injection in the geological reservoir

Fuel used in power plant	Amount of CO_2 transported to the injection site, t/day	CO_2 emissions from electricity consumption for	
		compression phase, t/day	pumping phase, t/day
Natural gas	2 643 t/day	52,191	3,963
Pulverized coal	5 456 t/day	222,383	16,894

Conclusions

The analysis shows the interrelations of CO_2 emissions generated during the injection and compression phases of CO_2 sequestration processes and stored CO_2 emissions. CO_2 generated in the injection phase is not significant in comparison with total amount of CO_2 stored in the geological storage - it produces approximately 0.1 % from CO_2 emissions sequestrated in the case of the gas power plant, and between 0.1- 0.3% for the coal burning energy plant.
The impact of the energy consumed for CO_2 compression and injection phases were also analysed with a life cycle analysis approach - *Ecoindicators 99*. The results show that the impact to the environment varies from 1% to 2.5 % from the total amount of CO_2 stored in the geological trap. These numbers are reliable for the Latvian energy sector, where a considerable proportion of primary energy is produced from renewable energy resources, such as hydro energy, and therefore the impact to climate change is lower.
To get more detailed results, it is necessary to include CO_2 transportation phase and additional booster stations, which were not discussed in this paper, in the process analysis.

References

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Gušča J., Demidko J., Blumberga D. Oglekļa dioksīda emisiju ģeoloģiskā uzglabāšana: enerģijas patēriņa modelis iesūknēšanas posmam

CO2 piesaistes un ģeoloģiskā uzglabāšana ir pasaulē atzīts siltumnīcefekta gāzu (SEG) emisiju izraisīto klimata pārmaiņu samazināšanas veids. Tomēr pats emisiju piesaistes un uzglabāšanas process ir saistīts ar paaugstinātu enerģijas patēriņu, kas iespaido arī kopējo sistēmas lietderības koeficientu. Aprakstītajā pētījumā tiek apskatīta oglekļa dioksīda saspiešanas un iesūknēšanas posmu ietekme uz vidi no procesu īstenošanai nepieciešamās elektroenerģijas patēriņa. Par atskaites enerģijas sistēmu tiek ņemta 400 MW elektroenerģijas stacija ar gadā saražoto elektroenerģijas daudzumu 2400000MWh pie diviem scenārijiem: ražojot elektroenerģiju no dabas gāzes un akmeņoglēm. Par oglekļa dioksīda emisiju uzglabāšanas vietu pētījuma ietvaros ir izvēlēts Snēpeles kolektorrezervuārs, kurš atrodas Latvijas rietumdaļā: rezervuārā ģeoloģiskie un hidroģeoloģiskie raksturlielumi manāmi ietekmē sūkņa jaudas izvēli un līdz ar to arī patērētās enerģijas daudzumu. Lai noteiktu saspiešanas un iepumpēšanas procesu ietekmi uz vidi, pētījumā tika izmantota dzīves cikla analīzes (DZA) Ekoindikatoru 99 metode un Latvijas energotirgum raksturīgais saražotās enerģijas ietekmes indikators. Ietekmju analīzes pilnveidošanai ir ieteicams papildināt pētījumu, veicot dzīves cikla analīzi ar specializētās datorprogrammas palīdzību.

Gusca J., Demidko J., Blumberga D. Geological storage of carbon dioxide emissions: energy consumption model for injection phase

CO2 capture and geological storage is a tool accepted worldwide for climate change mitigation caused by greenhouse gases (GHG). Nonetheless, the CO2 sequestration process consumes additional energy and affects the total efficiency of the energy production chain (incl. GHG reduction). The paper describes the impact of CO2 *compression and injection phases to the environment from energy consumption point of view. A 400MW power plant (2400000MWh electricity produced per year) is used as a reference plant for the analysis. It is assumed that electricity is produced from gas (1st scenario) and pulverized coal (2nd scenario). Snepele geological trap situated in the north-western part of Latvia is selected as the potential storage site. The geological and hydrogeological conditions of the trap affect the amount of electricity used for the injection phase. The Ecoindicators 99 method based on life cycle analysis (LCA) approach is used to determine the impact to the environment of the compression and injection phase. Energy indicator, specific for Latvian energy sector, is used in the LCA analysis. For future investigations it is recommeded to improve the impact assessment of the processes through the analysis with specialised LCA software.*

Гуща Ю., Демидко Е., Блумберга Д. Геологическое хранение выбросов углекислого газа: модель потребления энергии в процессе инжектирования

Улавливание и геологическое хранение выбросов углекислого газа является общепризнанным методом по уменьшению воздействия на окружающую среду и глобальное потепление. Однако сам процесс улавливания и хранения связан с повышенным потреблением энергии, что, в свою очередь, оказывает влияние на общую эффективность данной системы. В описанном исследовании рассматривается влияние процессов сжатия и закачки эмиссий углекислого газа на окружающую среду с точки зрения потребляемой в этих процессах электроенергии. За отчетную энергосистему в исследовании принята в рассмотрение электростанция мощностью 400 МВт, с годовой производительностью 2400000 МВтЧ. Рассматриваются два сценария работы данной электростанции: используя как топливо каменный уголь (1-ый сценарий) и природный газ (2-ой сценарий). Геологическая коллекторная ловушка на северо-западе Латвии- Снепеле - принята в исследовании как потенциальное место закачки эмиссий углекислого газа: характерные геологические величины ловушки влияют на дальнейшый рассчет и результаты выбора мощности насоса, и тем самым обёмом потребляемой электроенергии. Для оценки влияния процессов сжатия и закачки эмиссий на окружающую среду, в иссследовании применяется методика анализа жизненного цикла через метод Экоиндикаторов -99 и характерного для латвийского энергорынка индикатора произведенной электроенергии.