ECONOMICAL AND TECHNICAL ANALYSIS OF CO_2 TRANSPORT WAYS

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Large reductions in carbon dioxide (CO_2) emissions are needed to mitigate the impacts of climate change. One method of achieving such reductions is CO_2 capture and storage (CCS). CCS requires the capture of carbon dioxide (CO_2) at a large industrial facility, such as a power plant, and its transport to a geological storage site where CO_2 is sequestered.

The study also aims to develop a computer program, with which one can determine the best option for CO_2 transport using some initial data entry.

In this paper we have analyzed three methods of transport of CO_2 in the liquid such as: transport of CO_2 via pipeline, rail transport, road transport.

Keywords: CO_2 transport cost, CO_2 pipeline transport, CO_2 railroad transport, CO_2 tanker truck transport

1. Introduction

Climate changes become a global issue and actions aimed to reduce them can only be global especially since this is the main challenge facing the contemporary world. Capture and storage of CO_2 is today a viable option for reduction of greenhouse gas emissions.

The objective of this paper consists to compare different ways of CO_2 transport from the power plant to the storage site.

There are multiple options for transporting compressed CO_2 from the source to the geological sink. Practical modes of overland transport include motor carrier, rail, and pipeline. The most economic method of transport depends on the locations of capture and storage, distance from source to sink, and the quantities of CO_2 to be transported. However, the quantity to be transported is the dominant factor on the order of 2 to 3 million metric tons (Mt) per year of CO_2 would need to be transported from a single 500 MW coal-fired power plant. As a result, pipeline is the only viable option for overland transport [1, 2], and is the only method of transport considered in this study. There is considerable industrial experience in the transport of CO_2 by pipeline. Upwards of 50 Mt/y of CO_2 is

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transported over nearly 100 km of pipelines primarily for use in EOR operations [3, 4]. For comparison, this would be the amount of CO_2 produced by about sixteen-500 MW coal fired power plants.

2. Model description of the CO_2 transport ways

There have been few studies that have addressed the cost of carbon dioxide (CO_2) transport in detail. However, earlier work by Svensson et al. [2] identified pipeline transport as the most practical method to move large volumes of CO_2 overland and other studies have affirmed this conclusion. There is considerable experience in the transport of CO_2 by pipeline, as upwards of 50 million tons per year of CO_2 is transported over nearly 100 km of pipelines primarily for use in enhanced oil recovery (EOR) operations [3, 4]. This study focuses on the cost of CO_2 transport via pipeline, but, we have also study the CO_2 transport via camion and by train. In 1993, Skovholt [1] presented rules of thumb for sizing of CO_2 pipelines and estimated the capital cost of pipeline transport. In 2002, the International Energy Agency Greenhouse Gas Programme (IEA GHG) released a report that presented several correlations for the cost of CO_2 pipelines in Europe based on detailed case study designs [5].

In the figure 2.1., we have presented the ways to transport of the CO_2 from the power plant to the storage site. The results from each transport solution are compared with the other results in order to determine the optimal solution for a period life defined.

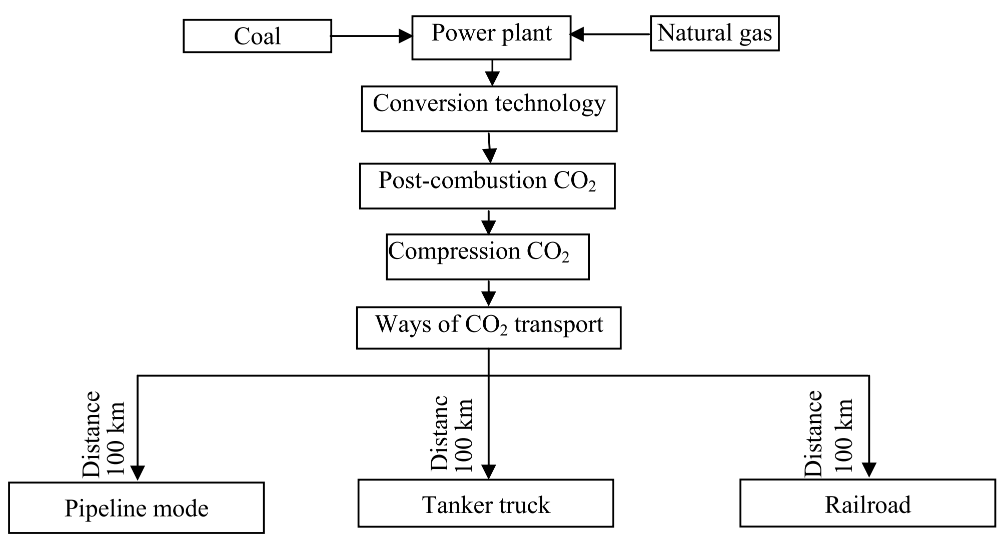

Fig. 2.1.Transportation modes.

Model of the pipeline CO_2 transport

To determine the optimum diameter for transport through the pipeline over the study period were taken into account a number of parameters including: CO_2 flow, suction pressure, discharge pressure, which was chosen according to the storage site, pipeline length, soil temperature, elevation, purity of transported CO_2, pipeline roughness. Suction pressure is set at 140 bars, while the discharge pressure is around 100 bars. A preliminary sizing is made depending of calculated viscosity on pipeline pressure and soil temperature. Taking into account the parameters described, we obtained the required diameter for the pipeline.

The performance model takes as input engineering design parameters, such as pipeline length and design CO_2 mass flow and calculates the required pipe diameter. The transport performance model includes a comprehensive physical properties model for CO_2 and other fluids of interest (e.g., H_2S); accounts for the compressibility of CO_2 during transport; allows booster pumping stations and segment elevation changes; and, includes probabilistic assessment capabilities. Figure 2.2. shows the inputs and outputs from the performance model, and how the performance model interacts with the pipeline cost model and the CO_2 properties model.

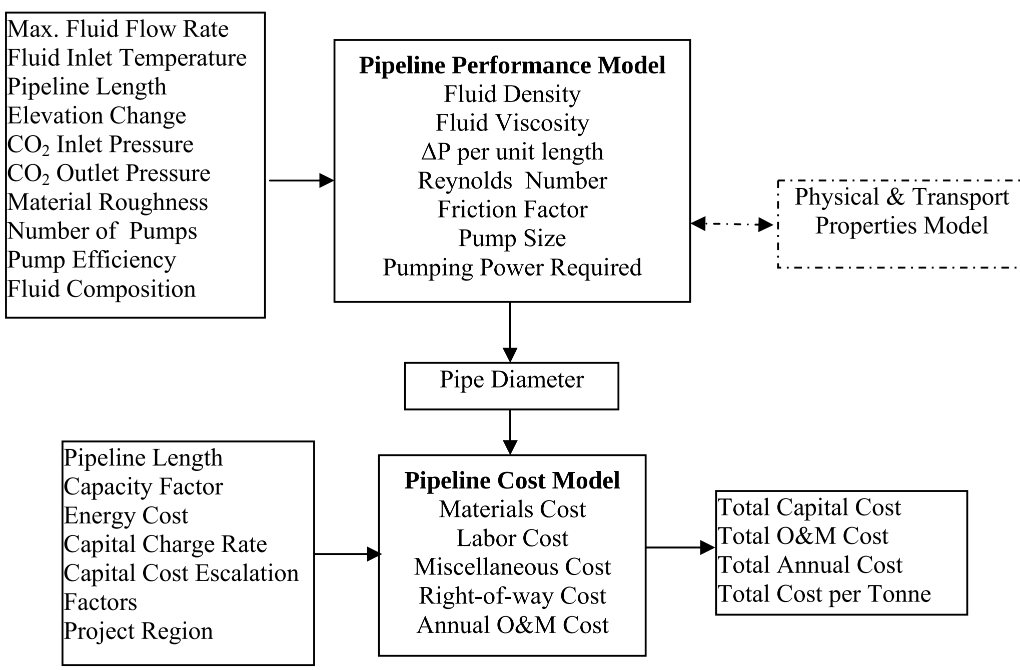

Figure 2.2. The model of the CO_2 pipeline transport

Efficient transport of CO_2 via pipeline requires that CO_2 be compressed and cooled to the liquid state [8].

The compressibility of CO_2 is non-linear in the range of pressures common for pipeline transport and is highly sensitive to any impurities, such as hydrogen sulfide (H2S) or methane (CH4) [4].

To reduce difficulties in design and operation, it is generally recommended that a CO_2 pipeline operate at pressures greater than 8,6 MPa where the sharp changes in compressibility of CO_2 can be avoided across a range of temperatures that may be encountered in the pipeline system [4]. The density of CO_2 varies between 800 kg/m3 and 1000 kg/m3 [3].

Operating temperatures of CO_2 pipelines are generally dictated by the temperature of the surrounding soil. In northern latitudes, the soil temperature varies from a few degrees below zero in the winter to 6-8^{o}C in summer, while in tropical locations; the soil temperature may reach up to 20^{o}C [1].

While there are proven flow equations available for use with high pressure gas pipelines (e.g. AGA fully turbulent equation), these equations can introduce error into the estimation of flow rates in liquid CO_2 due to the underlying assumptions made in their development [5]. The pipeline performance model used here is based on an energy balance on the flowing CO_2, where the required pipeline diameter for a pipeline segment is calculated while holding the upstream and downstream pressures constant.

Equation 2.1 can be used to calculate the pipe diameter required for a given pressure drop.

$$D_i = \left\{ \frac{-64 Z_{med}^2 R^2 T_{med}^2 f_F \dot{m}^2 \ L}{\pi^2 \left[M Z_{med} R T_{med} \left(p_2^2 - p_1^2 \right) + 2 g P_{med}^2 M^2 \left(h_2 - h_1 \right) \right]} \right\}^{1/5} \qquad (2.1)$$

In Equation 2.2: $\boldsymbol{g}$ is acceleration due to gravity; $\boldsymbol{g_c}$ is the conversion factor converting force units (in the SI system of units, this is equal to unity); $\boldsymbol{v}$ is the specific volume of fluid; $\boldsymbol{p}$ is pressure; $\boldsymbol{h}$ is height; $\boldsymbol{f_F}$ is the fanning friction factor; $\boldsymbol{D_i}$ is the pipeline diameter; and L is the length of the pipe segment.

The costs of pipelines can be categorized into three items [8]:

- ***Construction costs***: Material/equipment costs (pipe, pipe coating, cathode protection, telecommunication equipment; possible. booster stations); Installation costs (labor);
- ***Operation and maintenance costs***: Monitoring costs; Maintenance costs; (Possible) energy costs;

- ***Other costs*** (design, project management, regulatory filing fees, insurances costs, right-of-way costs, and contingencies allowances).

The cost of materials from which the pipeline is build depends by: pipeline length, amount of CO_2 transported and CO_2 purity.

The investment cost are higher when is necessary to install pumping stations in order to compensate pressure drop trough the pipeline over large distances or level differences. The installation of pumping stations can be avoided by increasing the pipeline diameter and by reducing the flow velocity. Flow velocity varies between 1-1,5 m/s [9].

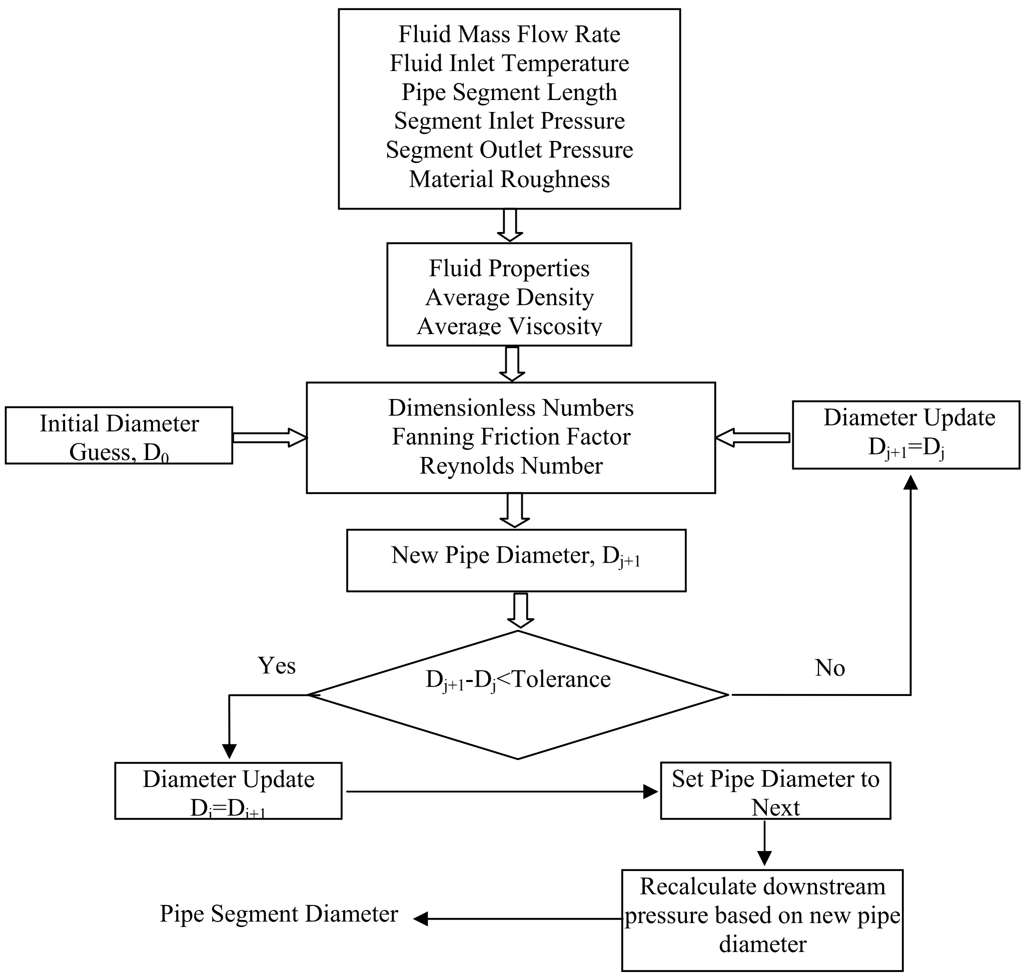

Fig. 2.3. Flowchart illustrating the method used to estimate the pipeline segment diameter

The economic equations used to identify the each cost of pipeline are presented bellow.

The equation for the materials cost is:

$$C_m = 64632\$ + 1{,}85\$ \times L \times \left(330{,}5 \times D^2 + 686{,}7 \times D + 26960\right) \tag{2.2}$$

The relation used to determine the right-of-way cost is depending of the number of the countries where the:

$$C_{ROW} = 48037\$ + 1{,}2\$ \times L \times \left(577 \times D + 29788\right) \tag{2.3}$$

The relation used to determine the labor cost is:

$$C_{lab} = 341627\$ + 1{,}85\$ \times L \times \left(343{,}2 \times D^2 + 2074 \times D + 170013\right) \tag{2.4}$$

The relation used to determine the miscellaneous cost is:

$$C_{mis} = 150166\$ + 1{,}58\$ \times L \times \left(8417 \times D + 7234\right) \tag{2.5}$$

The total capital cost of a reciprocating compressor station has been estimated by the IEA for a European study involving the pipeline transmission of CO_2 [10]. Pressure losses along the pipeline are very important, determining the number of pumping stations, it is necessary to maintain the desired discharge pressure (100 bars) at the storage site.

$$C_{comp} = 8{,}35 \times P_c + 0{,}49 \tag{2.6}$$

where P_c is the installed booster station power in MW.

2.1. Model of the tanker truck CO_2 transport

Transportation of CO_2 with a tank truck is a flexible modality and easily adaptable. To make things easy in this paper the number of drivers is considered equal with the number of tanker, and in order to keep costs down all the trucks were rented trough the entire period of transportation from the power plant to the storage site.

Annual quantities which can be transported with a truck depend first of all by the transport capacity of the tanker but also the distance between storage site and power plant. In order to determine the annual fuel consumption we taking into account the total distance but also the truck consumption (full or empty)

Total annual expenditure for this transport alternatives are given by the sum of fuel expenses, rent tanks, with maintenance costs and labor.

$$C_T = C_{Tfuel} + C_{Trent} + C_{TO\&M} + C_{Tlab} \quad (2.7)$$

2.2. Model of the railroad CO_2 transport

Railroad system has a large capacity of transportation which allowed transporting large amounts of CO_2 over a longer distance. This method of transportation is a viable option and also very competitive one as long the necessary infrastructure is provided but whit all this loading installations, storage containers make it more expensive mode of transport.

In order to determine an actual cost per ton of CO_2 transported with this method, we take into consideration the transport capacity per one train, considering electrical power, the velocity of the gas, the total distance and last but not least the power consumption.

$$C_{TE} = E \times N_d \text{ [MWh/year]} \quad (2.8)$$

Expenditure on rent per year [€ / year]. A solution of economically viable in terms of CO_2 transport, by train and railway is the rental of trucks throughout the journey. Total expenditure is the sum total annual energy costs, plus rent and labor costs.

$$C_T = C_{TE} + C_{Trent} + C_{Tlab} \quad (2.9)$$

3. Technical and economical comparative analysis of the CO_2 transport ways

In this paper we have analyzed three methods of CO_2 transport in the liquid such as: transport of CO_2 via pipeline, rail transport and road transport.

In the analysis of transportation alternatives, we started from a central facility equipped with CO_2 retention, with an efficiency of 90%, defined by an annual duration of operation, generating a constant flow of carbon dioxide to be transported from storage site.

The operational period of the power plant will be about 30 years during which in this time it was assumed that the flow of CO_2 was constant.

The optimal transportation method depends by the location where the power plant is installed and the storage site, distance between the two locations and the amount of CO_2 that required to be transported. However the amount of

CO_2 is estimated in millions of tons per year and is the main factor to be considered.

During this comparative analysis we started to identify the parameters which influence the capital expenditure such as: power plant output, overall efficiency, and carbon content of fuels, efficiency of the capture process, soil temperature, annual operating time, suction pressure and transport distance.

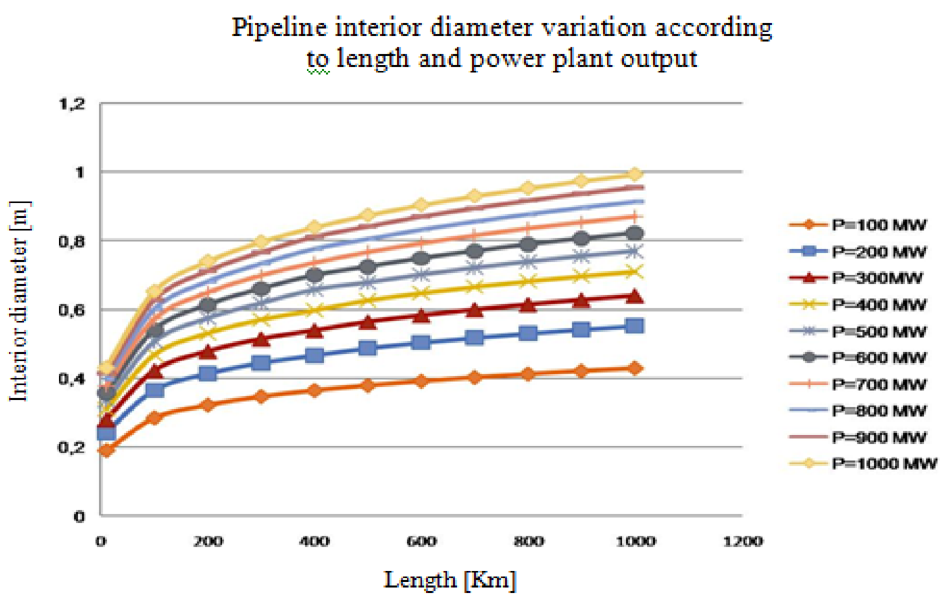

Fig.3.1. The plant runs on coal, capture efficiency = 0.9 Annual duration of operation = 5000 hours / year, T-p_med constant fuel composition

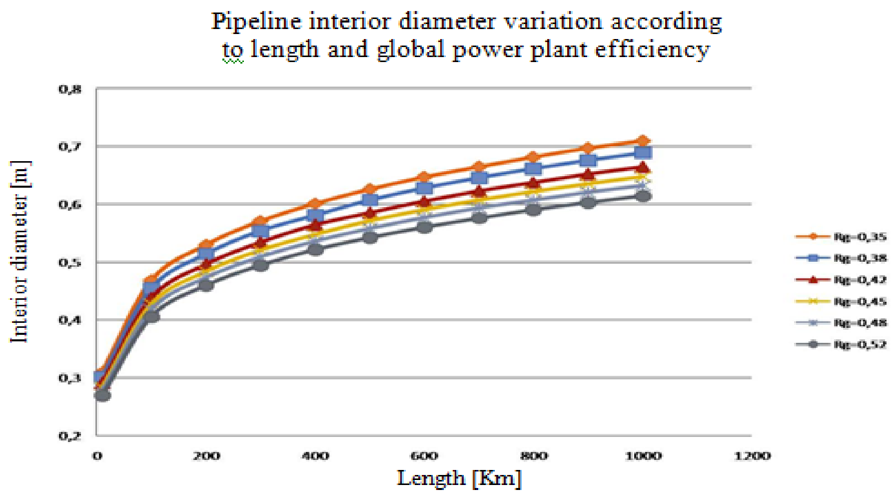

Fig. 3.2. The plant runs on coal, P=400 MW, capture efficiency = 0.9 Annual duration of operation = 5000 hours / year, T-p_med constant fuel composition

We observe in the figures 3.1. and 3.2. that the pipeline interior diameter is depending on the distance between the power plant and the storage site. The variation of the pipeline interior diameter is more important for a big power plant (P = 1000 MW) comparative with a small power plant (P = 100 MW). In this case the pipeline interior diameter presents a variation with 250 % for a big power plant if the distance between the power plant and the storage site grows from the 100 km to 1000 km. Contrarily, for a small power plant the pipeline interior diameter varies with 100 % in the same conditions.

The global efficiency of the power plant has not an important influence of the pipeline interior diameter. For the length between the power plant and the storage site more than 1000 km, and for an increasing with 50 % of the global efficiency power plant, the pipeline interior diameter is reduced with only 10 %.

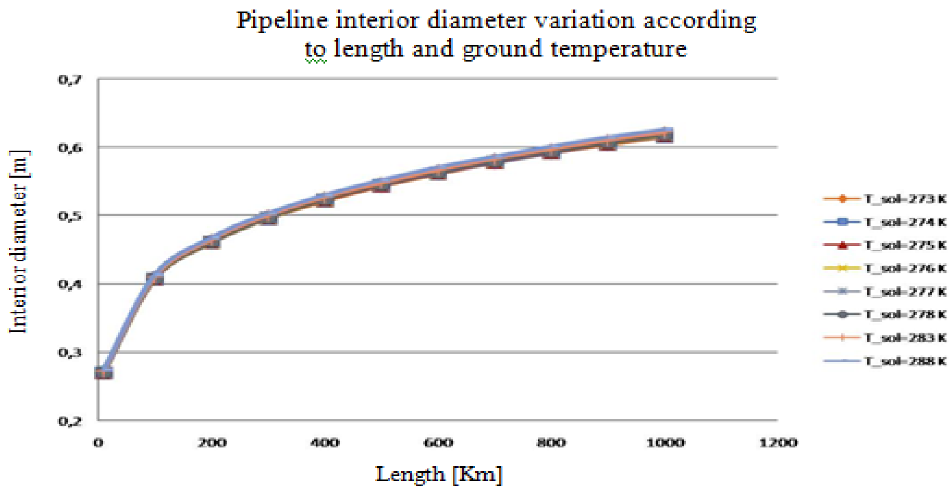

Fig. 3.3. The plant runs on coal, P=400 MW, capture efficiency = 0.9 Annual duration of operation = 5000 hours / year, T-p_med constant fuel composition

The variation of the pipeline interior diameter with the distance between the power plant and the storage site for different ground temperature and for different carbon content in the fuel is not significant (figure 3.3 and 3.4). So we have the same pipeline interior diameter for anthracite and for lignite as a fuel in the power plant. The same conclusion has been observed if the CO_2 transport is developed in different regions.

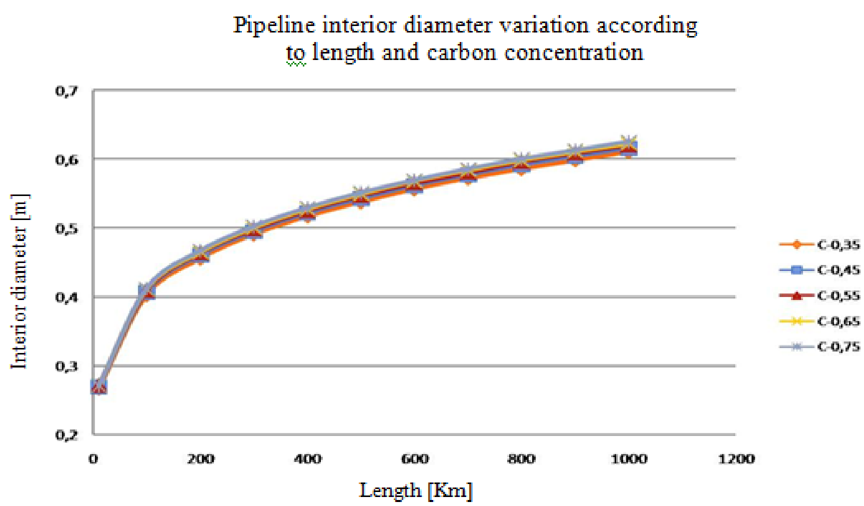

Fig. 3.4. The plant runs on coal, P=400 MW, capture efficiency = 0.9 Annual duration of operation = 5000 hours / year

4. Conclusions

In the economic comparative analysis of the three CO_2 transport ways taking into account the power plant lifetime, the CO_2 pipeline transport way is rentable for a power plant life time bigger than 23 years. Otherwise, the road and the rail transport are preferred instead pipeline transport (figure 4.1).

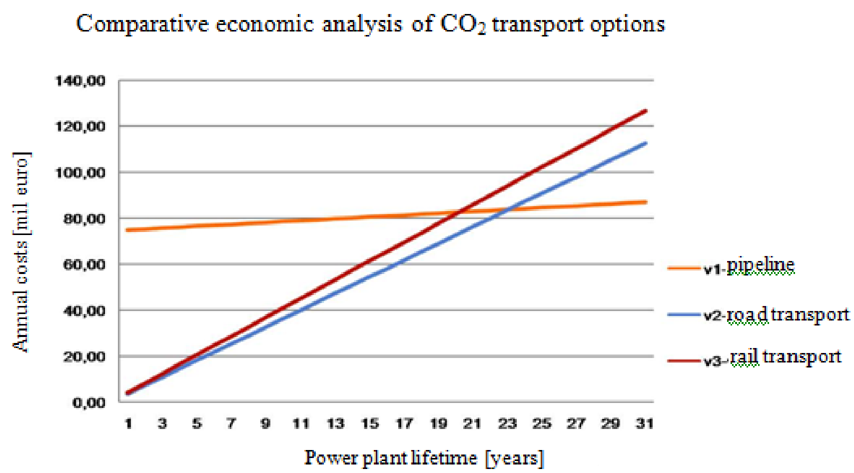

Fig. 4.1. The plant runs on coal, P=400 MW,L=100 Km capture efficiency = 0.9 Annual duration of operation = 5000 hours / year

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