WH2P and its contribution to: resource and energy efficiency, reduction of primary energy, and reduction of GHG emissions

The use of waste heat has attracted a significant amount of research attention. Industrial processes are known to discharge sufficient amounts of waste heat in a wide range of temperatures, while according to (Forman, et al., 2016), who estimated the waste heat potential of the major common sectors of end use including global electricity generation, about 72% of the total global energy input is lost after conversion and about 51% is lost as waste heat, as depicted in Figure 1.

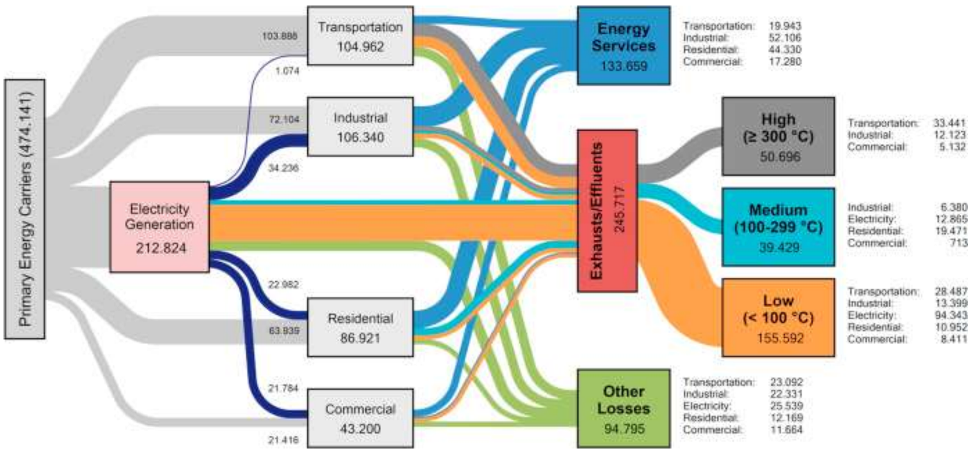

Figure 1 Estimated global waste heat distribution of 2012 in PJ (Forman, et al., 2016)

The utilization of industrial waste heat can lead to environmental benefits deriving from the reduction of resource consumption and greenhouse gas emissions, as well as economic benefits from the reduction of fuel cost (Chae, et al., 2010) (Sun, et al., 2014)

WH2P contribution to resource and energy efficiency:

(Sui, et al., 2014) investigated the energy-saving effect of a Waste Heat to Power (WH2P) project concerning the life cycle of a selected cement production process. In this context, the authors conducted an Exergetic Life Cycle Assessment (ELCA) and focused on the energy and exergy efficiency of the system before (Case 1) and after (Case 2) the implementation of the low temperature WH2P. Regarding the ELCA methodology, it integrates the general Life Cycle Assessment (LCA) framework (ISO 14040, ISO 14044) with exergy analysis in order to assess the resource consumption, environmental impact and energy consumption of the system though its whole life cycle. Specifically, the system boundaries of the study include the subsystems of raw material preparation, pulverized coal preparation, and rotary kiln system, with the ultimate goal of obtaining the exergy efficiency of each subsystem while investigating resource and energy utilization. The low temperature WH2P system is composed of two sets of waste heat recycling boiler and one set of condensing steam turbine generator with a nominal capacity of 7.5MW. Moreover, the electric energy that is produced by the generator is used in the clinker production line (4500 t/day). The results of the study, which are depicted in Figure 2, indicate that the implementation of the WH2P system **leads to increased energy and exergy efficiency**. Specifically, concerning the raw material preparation system the energy and exergy efficiency of Case 1 are 39.5% and 4.5% respectively, while for Case 2 these values are 45.8% and 7.8% respectively. Furthermore, concerning the pulverized coal preparation system, the energy and exergy efficiency of

Case 1 are 10.8% and 1.4% respectively, while for Case 2 these values arise to 15.5% and 2.8% respectively. Finally, concerning the rotary kiln system, the energy and exergy efficiency of Case 1 are 50.2% and 33.7% respectively, while in Case 2 these values are 55.1% and 38.1% respectively.

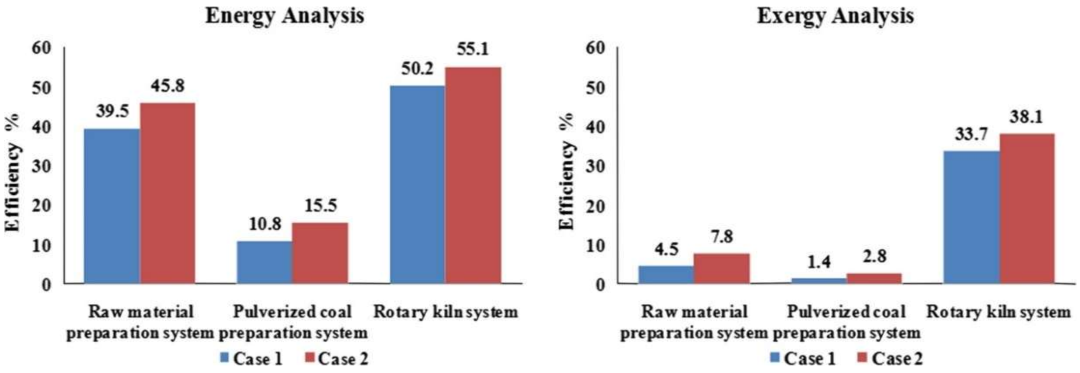

Figure 2 Objective energy and exergy efficiency of each system (Sui, et al., 2014)

The kiln system is identified as the most complicated among the examined systems as it includes more than just heat transfer, namely coal combustion, raw material decomposition, clinker formation and a series of chemical reactions. In order to investigate the exergy utilization of the rotary kiln system in more comprehensive manner, the authors generated exergy balance diagrams for cases 1 and 2, which are presented in Figure 3. When comparing the two diagrams it is concluded that the difference of irreversible exergy losses between the two cases is minor but in Case 2 the recycled exergy accounts for about 9% of the production revenue deriving from the WH2P generation system. The electricity exergy of the WH2P accounts to 3.7% of the rotary kiln system's total input, while the implementation of the WH2P system causes an objective exergy efficiency increase of 3.3%, 1.4% and 4.4% for the systems of raw material preparation, pulverized coal preparation and rotary kiln respectively. The authors conclude that the WH2P generation project can provide **significant economic and environmental benefits**.

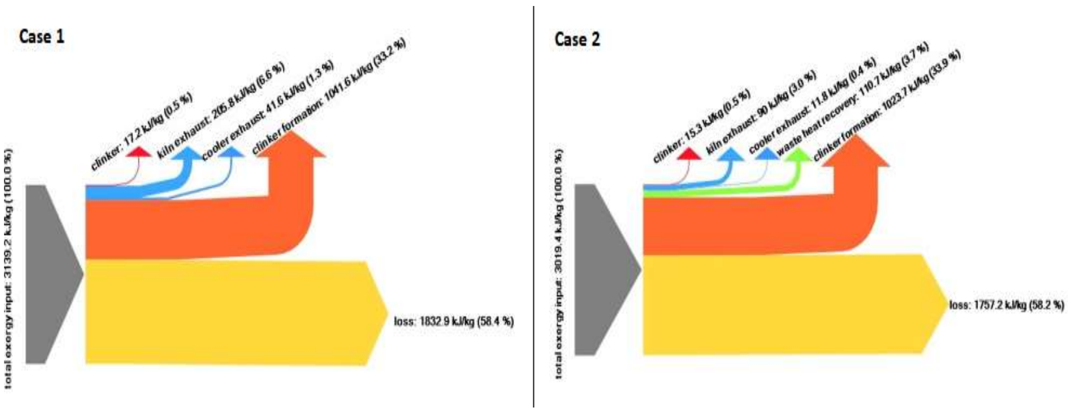

Figure 3 Comparison of the exergy balance of rotary kiln system between Case 1 and Case 2 (Sui, et al., 2014)

WH2P contribution to reduction of primary energy:

In a similar but more thorough context, the exploitation of waste heat of a power generation plant was studied by (Iyer & Pilla, 2021) who conducted a LCA of thermoelectric (TE) modules applied on a traditional baseload coal-based power plant with continuous waste heat emissions, taking into account a wide range of environmental impact categories. Specifically, the study's goal is the evaluation of the environmental benefits that derive from the implementation of TE modules over their whole life cycle, namely through the phases of extraction and processing of their elements, manufacturing of module components, operation, and final decommission. Seven commercial/near-commercial TE modules were evaluated in total, namely two each of bismuth-telluride (BT) and skutterudite (SK) systems, and one each of Half-Heusler (HH), lead-telluride (PT), and silicide (SC) systems.

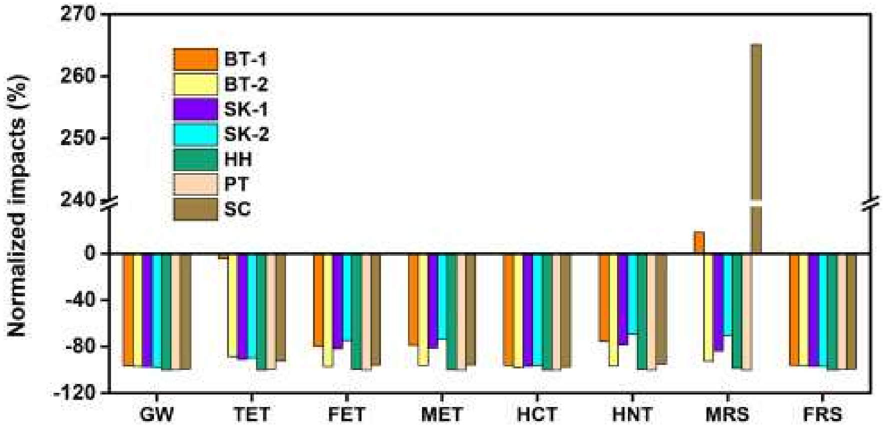

Figure 4 Life cycle impacts of chosen thermoelectric modules, based on considered functional unit (Iyer & Pilla, 2021)

Regarding the functional unit, it is assumed that each module is used as a set of two or more modules connected in series in order for each set to convert 1000 W of input waste heat power (emitted from the baseload coal-based power plant) to electricity. Moreover, the functional unit is defined as 1 kWh of electricity generation from the aforementioned set. Concerning the operation stage, the authors assumed that the TE modules lower coal-based electricity generation, and therefore the associated coal use, by the energy amount the produce. The study's results show that TE modules **exhibit significant environmental benefits** [depicted in Figure 4, abbreviations: global warming (GW), fossil resource scarcity (FRS), human toxicity – carcinogenic (HCT) and non-carcinogenic (HNT), ecotoxicity – terrestrial (TET), freshwater (FET) and marine (MET), and mineral resource scarcity (MRS)] including lowering the use of scarce fossil fuels and thus contributing to the reduction of primary energy use. As can be seen from Figure , when excluding BT-1 and SC modules on MRS category, all modules **show net positive effects on environment** on all assessed impact categories, mainly due to the predominant beneficial effect of the operation stage of these modules, which **reduces the need for coal-based electricity generation from the baseload plant**, and thus, its associated impacts. The authors conclude that the study's results mark TE as an excellent complementary technology regarding the exploitation of waste heat across both fossil and renewable energy plants, thus helping to replace coal-based electricity with renewable energy in order to achieve the transition to a cleaner grid mix.

WH2P contribution to reduction of GHG emissions:

The exploitation of waste heat for heating purposes was studied by (Baidya, et al., 2019) who presented a techno-economic analysis regarding the feasibility of waste heat recovery from diesel generator (which operate in Canadian mines) exhaust streams and investigated the potential energy and economic savings. It is mentioned that in order to generate 1 kW of electricity, 2.5-3 kW worth of diesel has to be consumed and 1.7-2 kW worth of diesel is rejected, while 1 kW of the latter is lost in the exhaust streams (assuming an 100% load factor). Regarding the used methodology, a simple Exhaust Heat Recovery (EHR) system was designed and implemented for intake air heating of an underground mine (Case A) and space heating/domestic hot water supply (Case B), while thermodynamic modeling and energy analysis were implemented in order to assess the system's feasibility. The study's results show that the implementation of the proposed EHR system is beneficial as it's able to provide about 67% of the total heat demand of the mine for intake air heating (which represents the highest demand) and 100% of space heating applications.

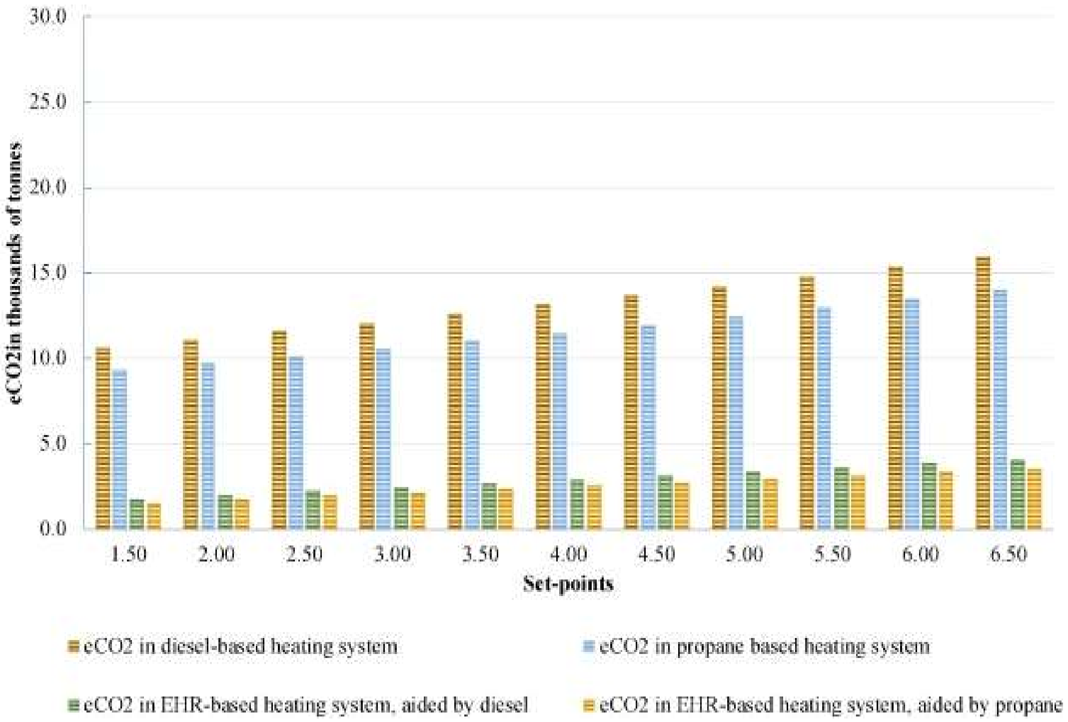

Figure 5 LCA of the analyzed underground mine's annual intake air heating with and without the proposed EHR system for several set-point temperatures, assessed location: British Columbia (Baidya, et al., 2019)

Moreover, the authors also conducted a LCA in order to calculate the CO_2-eq impact of fossil fuel consumption for both the conventional heating system and the proposed heating system (used to preheat the mine's intake air). From the results of the LCA (which are presented indicatively for the case of British Columbia in Figure 5) it is concluded that if the conventional diesel-based heating system is replaced by the proposed EHR, **the CO_2 emissions can be reduced by 3-5 times** depending on the location, while in the case of propane-based heating system, **the CO_2 emission reduction can be 2.5-4.5 times**. The authors mention that the deployment of such waste heat recovery systems can lead remote mining towards an energy/economic efficient and sustainable operation while significantly reducing its lifecycle carbon footprint.

References

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