Potential Of Waste Heat And Waste Cold Energy Recovery In Singapore For District Cooling Applications: Impacts On Energy System

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Overview

Currently, most of the cooling energy demand of Singapore is met by electrically driven devices, such as air-to-air heat pumps (split units) or electric chillers. A significant amount of waste heat and waste cold is available in Singapore, as a part of power generation in gas power plants, waste incineration plants and the cold released during the LNG regasification process. Waste heat could be utilized via absorption chillers to convert it in cooling energy and distribute it to the consumers via district cooling grid, increasing energy efficiency and reducing power consumption; while LNG cold released during gasification process could be directly utilized. In order to assess this potential, smart energy system was modelled in energy balance hourly simulation tool in order to investigate the impact of district cooling on the energy system of Singapore. Business-As-Usual (BAU) and District Cooling (DC) scenarios were developed for the year 2030 and 2050. Results showed that CO2 emissions could be reduced by 11.5% and 9.9% in years 2030 and 2050 compared to the BAU scenario. Primary energy demand could be reduced by 12.2% and 10.2%, while total socio-economic costs could be 4.6% and 3.8% lower. Thus, it was concluded that although infrastructure investment in district cooling would be significant in the initial phase, benefits in terms of energy savings and reduced gas imports are more significant, resulting in the lower socio-economic costs of the energy system than in the case without district cooling being implemented. Finally, potential for the district cooling from waste heat was estimated for the South-east Asia's energy system anticipated in the year 2040.

Methods

In order to simulate the energy system of Singapore, as well as to simulate the system with the introduction of a plausible district cooling grid, the 'EnergyPLAN' energy balance simulation tool was used [1]. The EnergyPLAN modelling tool is freeware software, especially suitable for modelling integrated energy systems with increased shares of intermittent generation. It has been used for modelling of energy systems in the European Union [2], regions such as South-east Europe [3], a range of other countries, cities and islands [1].

Total socio-economic costs of the energy system, primary energy demand and CO2 emissions were chosen as indicators for the comparison of different scenarios. Total socio-economic costs included levelized investment costs, fixed and variable operating and maintenance costs, fuel costs and carbon tax. Carbon tax was considered as an internalized negative externality of climate change costs; hence, it was included in the socio-economic costs estimation, unlike the other taxes, as those were considered to be internal redistributions of wealth within society.

EnergyPLAN was used to develop different scenarios for the years 2030 and 2050, along with a reference scenario created to validate the model by comparing it with the already available energy statistics for Singapore. Two scenarios for each of the years 2030 and 2050 were developed; i.e. one with and one without district cooling infrastructure (i.e. DC 2030 and no-DC 2030 and DC 2050 and no-DC 2050). The no-DC scenario included expected measures in terms of energy efficiency in industry and buildings, as well as stable increases in PV penetration and electric mobility. Furthermore, it included expected declines in the energy intensity of the country by extrapolating the current trend up to the year 2050 [18]. The two scenarios including district cooling (DC 2030 and DC 2050) added that infrastructure component on top of the measures already implemented in no-DC 2030 and no-DC 2050 scenarios.

Results

The main, currently untapped, sources of energy for cooling taken into account in this study were the cold avilable from the LNG gasification terminal and waste heat from gas power plants and waste incineration plants. Waste heat from gas power plants and waste incineration plants can be recuperated at suitable temperature levels, i.e. 90 ^{o}C, and utilized via single effect absorption chillers to produced cooling energy that can be fed into the grid. Results of the cold potential from these different sources is presented in Table 1, while the estimated infrastructure costs are presented in Table 2.

Table 1. Sources for district cold

	GWh waste heat	COP absorption chillers	Cold 2014 [GWh]	Cold 2030 [GWh]	Cold 2050 [GWh]
Gas Power Plants	52,031	0.7	36,422	36,877	24,286
Waste incineration plants	8,154	0.7	5,708	6,406	4,927
LNG gasification			463	2,251	1,104
Total			42,593	45,534	30,317

Table 2. Estimated infrastructure costs for district cooling grid in years 2030 and 2050

	2030	2050
District cooling grid cost [USD]	3,374,570,514	2,281,317,997
Technical lifetime [USD]	40	40
Fixed O&M [USD/year]	42,182,131	28,516,475

Primary energy demand was found to be significantly lower in scenarios that included a district cooling grid, i.e. it was 12.2% and 10.2% lower in the years 2030 and 2050. Furthermore, CO2 emissions were also reduced in the scenarios that included district cooling systems. For years 2030 and 2050, CO2 emissions were lower 11.5% and 9.9% than in scenarios that did not include a district cooling system. The total socio-economic costs were also lower in both scenarios that included a district cooling grid.

Moreover, there is a significant potential for utilization of district cooling in the whole of SE Asia as the region's economies develop. IEA noted in their projections that the capacity in the SE Asia's power sector will triple by 2040, increasing generation capacity by 400 GW, the majority of this new capacity being represented by coal power plants [4]. Clearly this significant additional new capacity that is envisaged in this area will also create large-scale opportunities for waste heat recovery. In 2040, it is envisaged that in SE Asia 2,837 TWh, 1,081 TWh and 267 TWh of electricity will be generated from coal, gas and bioenergy powerplants, respectively [4]. If all of this electricity is produced in power only plants, more than 2,000 TWh of waste heat will be rejected to the environment. Thus, a significant opportunity presents itself for Singapore, an already developed economy, to initiate research and development of district cooling for the region and play a pivotal role in transferring knowledge and a know-how to neighbouring countries.

Conclusions

- District cooling systems appear to be a viable investment in both targeted years, i.e. in years 2030 and 2050.
- Benefits of integration of district cooling in Singapore's energy systems are potentially threefold: it lowers total socio-economic costs, reduces CO2 emissions and increases efficiency of the energy system.
- Finally, additional benefits of a district cooling system could be quantified in future research, such as curbing the heat island effect and recovering additional energy being wasted currently, such as from large data centers.

References

[1] EnergyPLAN n.d. http://www.energyplan.eu/smartenergysystems/ (accessed October 4, 2015).

[2] Connolly D, Nielsen S, Persson U. Heat Roadmap Europe 2050. Second pre-study for the EU27. 2013.

[3] Dominković DF, Bačeković I, Ćosić B, Krajačić G, Pukšec T, Duić N, et al. Zero carbon energy system of South East Europe in 2050. Appl Energy 2016. doi:http://dx.doi.org/10.1016/j.apenergy.2016.03.046.

[4] International Energy Agency (IEA). Southeast Asia Energy Outlook. 2015.