Emission Inventory by Diesel Locomotives:
Evaluating the Economic and Environmental Impacts of Locomotive Renovation Policy for Iran National Railroad Network

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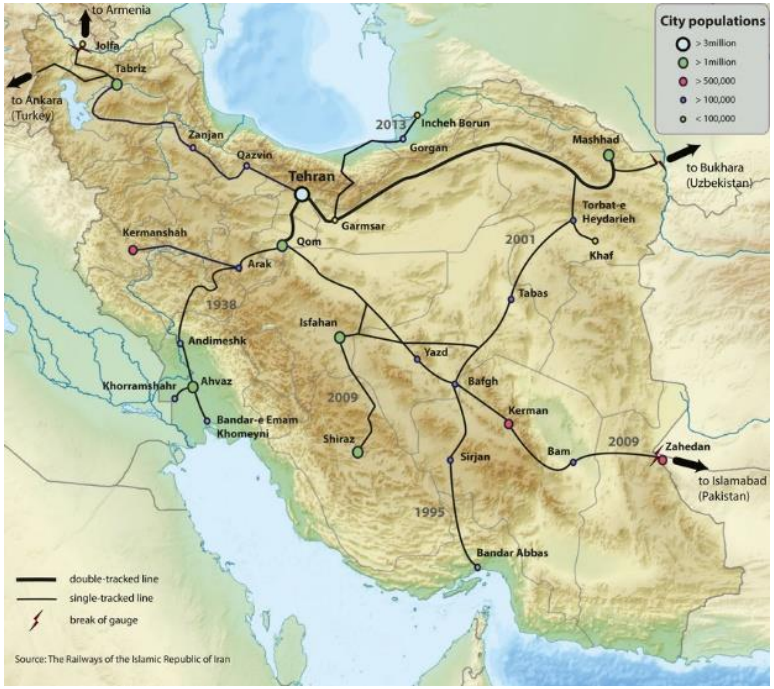
Background

- The Railways of the Islamic Republic of Iran (RAI) is jointly used for cargo and passenger transportation.
- The RAI network has 368 blocks, 9992 km of rail lines (including the second line on the double-tracked lines) and 364 stations which 44 stations are categorized as a “classification yard”



Background

- The pollutant emission of RAI is caused by:
  - Train stops at stations
  - Moving trains in the RAI network
- Old locomotives activity are considered as one of the main sources of air pollution, especially in such suburban area in Iran.
- For instance, Annually emission due to train stops in Tehran railway station is estimated at 2500 ton.
- As Iran national railroad locomotives are usually manufactured before 2001, this research is investigating the impact of locomotives renovation policy on air pollution.

Characteristics of RAI Locomotives

- The RAI daily activity is about 5200 loc.hour (62% Passenger trains)

No.	Loc.	Percent of all loc.	HP	Product Year	Company
1	G8	2.00%	875	1957	General Motors EMD
2	G12	19.80%	1310	1956 - 1958 - 1961	
3	G16	2.91%	1800	1957	
4	G18W	0.29%	1000	1958	
5	G22W	5.97%	1500	1975 - 1982	
6	GT26CW	38.28%	3000	1971 - 1974 - 1975- 1983- 1984	
7	U30C	4.80%	3000	1992- 1993	GE Transportation
8	C30-7i	4.22%	3000	1992- 1993	
9	HD10-C	5.53%	965	1971 - 1973 - 1975	Hitachi
10	LDE626CL-2	1.46%	1885	1986	Electroputere/ALCO
11	AD43C freight	10.04%	4300	--	Alstom
12	AD43C PASSENGER	3.64%	4300	--	
13	R-C-4	1.16%	4680	1982	ASEA

The Method of Emission Calculation

- In order to calculate emission in form of PM, NOx, CO, and HC, following formula is used:

$$\mathbf{E = N \times HP \times HRS \times EF}$$

- **E**: Amount of pollutant emission (gr)
- **N**: Number of locomotives
- **HP**: Locomotive horsepower (bhp)
- **HRS**: Hourly average of locomotive activity (hr)
- **EF**: Emission factor of pollutant (gr/bhp-hr)

The Method of Emission Calculation

- In order to calculate emission in form of CO_2 and SO_2, following formula is used:

$$\mathbf{M_i = A_i \times B_i \times CF_i \times D}$$

- $\mathbf{M_i}$: The mass of the i-th (CO_2 or SO_2) pollutant (grams per gallon of fuel consumed)
- $\mathbf{A_i}$: The mass of the i-th pollutant (CO_2 or SO_2) relative to mass of its element (C or S)
- $\mathbf{B_i}$: The percentage of the i-th pollutant element (C or S) in the fuel
- $\mathbf{CF_i}$: The percentage of Effective combustion on diesel engine (%)
- **D**: Fuel density (grams per gallon)

Notch Distribution of RAI Loc. (average)

Notch	Dynamic Brake	Idle	1	2	3	4	5	6	7	8
Time activity in duty cycle (%)	12.5	38	6.5	6.5	5.2	4.4	3.8	3.9	3	16.2
Power (hp)	15	8	222	339	735	993	1322	1704	2389	2823
Fuel consumption rate (lb/h)	33	18	95	134	274	364	434	615	841	991

Estimation of Emission Factor

- The pollutant emission factor is estimated by considering manufacture year of RAI loc.

EF of RAI current locomotives

EF of new locomotives

Table 1 - Line-Haul Emission Factors (g/bhp-hr)

	PM_{10}	HC	NO_x	CO
UNCONTROLLED	0.32	0.48	13.00	1.28
TIER 0	0.32	0.48	8.60	1.28
TIER 0+	0.20	0.30	7.20	1.28
TIER 1	0.32	0.47	6.70	1.28
TIER 1+	0.20	0.29	6.70	1.28
TIER2	0.18	0.26	4.95	1.28
TIER 2+ & TIER 3	0.08	0.13	4.95	1.28
TIER 4	0.015	0.04	1.00	1.28
+ INDICATES THAT THESE ARE THE REVISED STANDARDS IN 40 CFR PART 1033				

Source: Emission Factors for Locomotives (report), EPA, 2009

Definition of Renovation Scenarios

- In order to analyze the environmental and economic effect of RAI locomotive renovation, 4 scenarios in addition to the baseline scenario (The current state) was defined:

1. 20 percent renovation of RAI locomotives, named **Sc1**
2. 40 percent renovation of RAI locomotives, named **Sc2**
3. 60 percent renovation of RAI locomotives, named **Sc3**
4. 80 percent renovation of RAI locomotives, named **Sc4**

- All of the new locomotives are applied in the longest railway routes for calculating emissions in this study.

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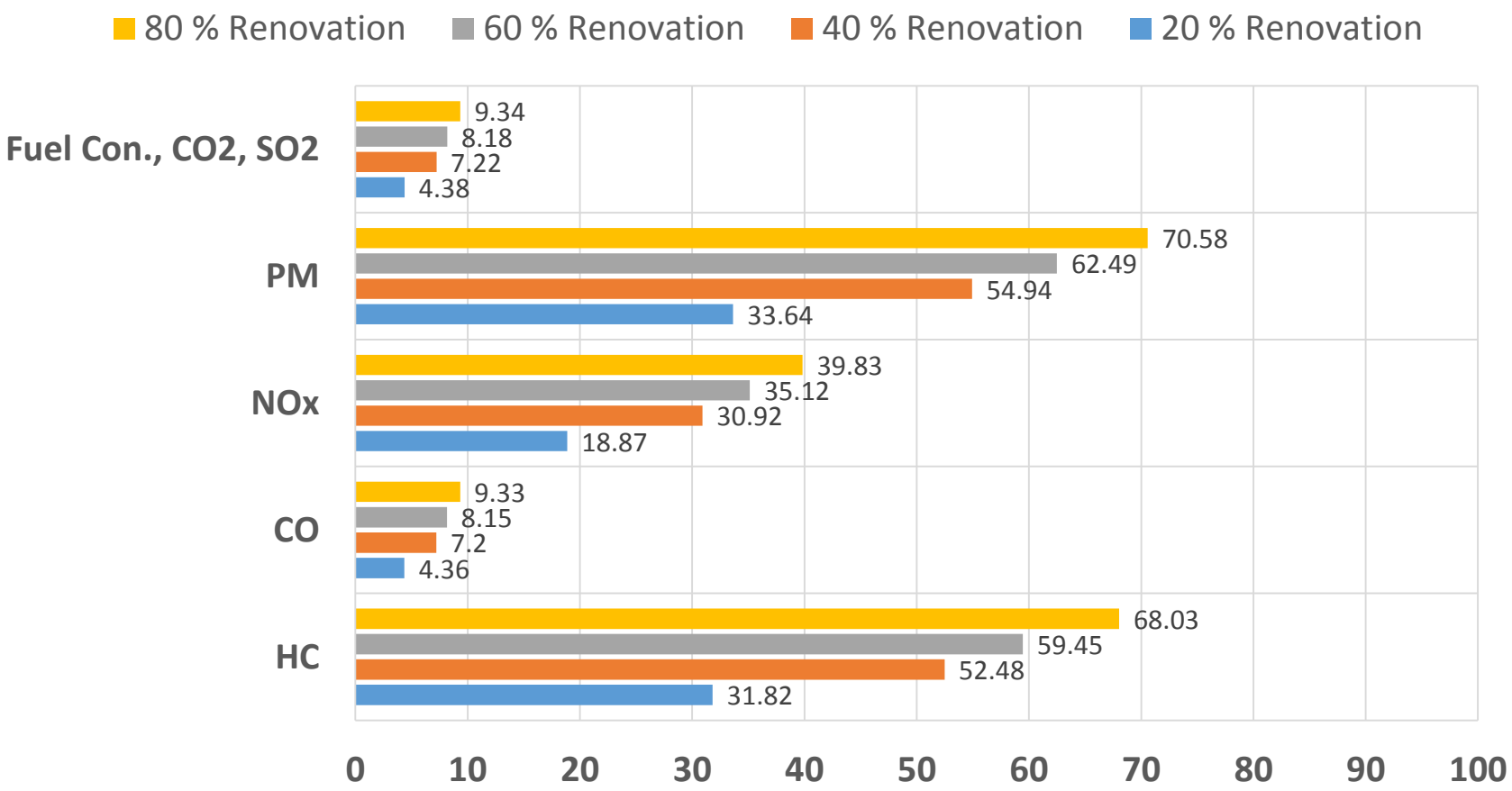
Annual Emission Inventory for All of Scenarios

Scenarios	HC (ton)	CO (ton)	NOx (ton)	PM (ton)	Fuel Consumption (ton)	CO2 (ton)	SO2 (ton)
Current State	461.4	1230.4	9286.3	366.3	163674	142583.0	1114.4
A: 20 % Renovation	314.6	1176.7	7533.6	243.1	156504	136336.4	1065.6
B: 40 % Renovation	219.2	1141.9	6414.9	165.0	151863	132293.8	1034.0
C: 60 % Renovation	187.1	1130.1	6024.6	137.4	150288	130921.9	1023.3
D: 80 % Renovation	147.5	1115.6	5587.3	107.7	148385	129264.2	1010.3

Percentage decrease of emission for All Scs.



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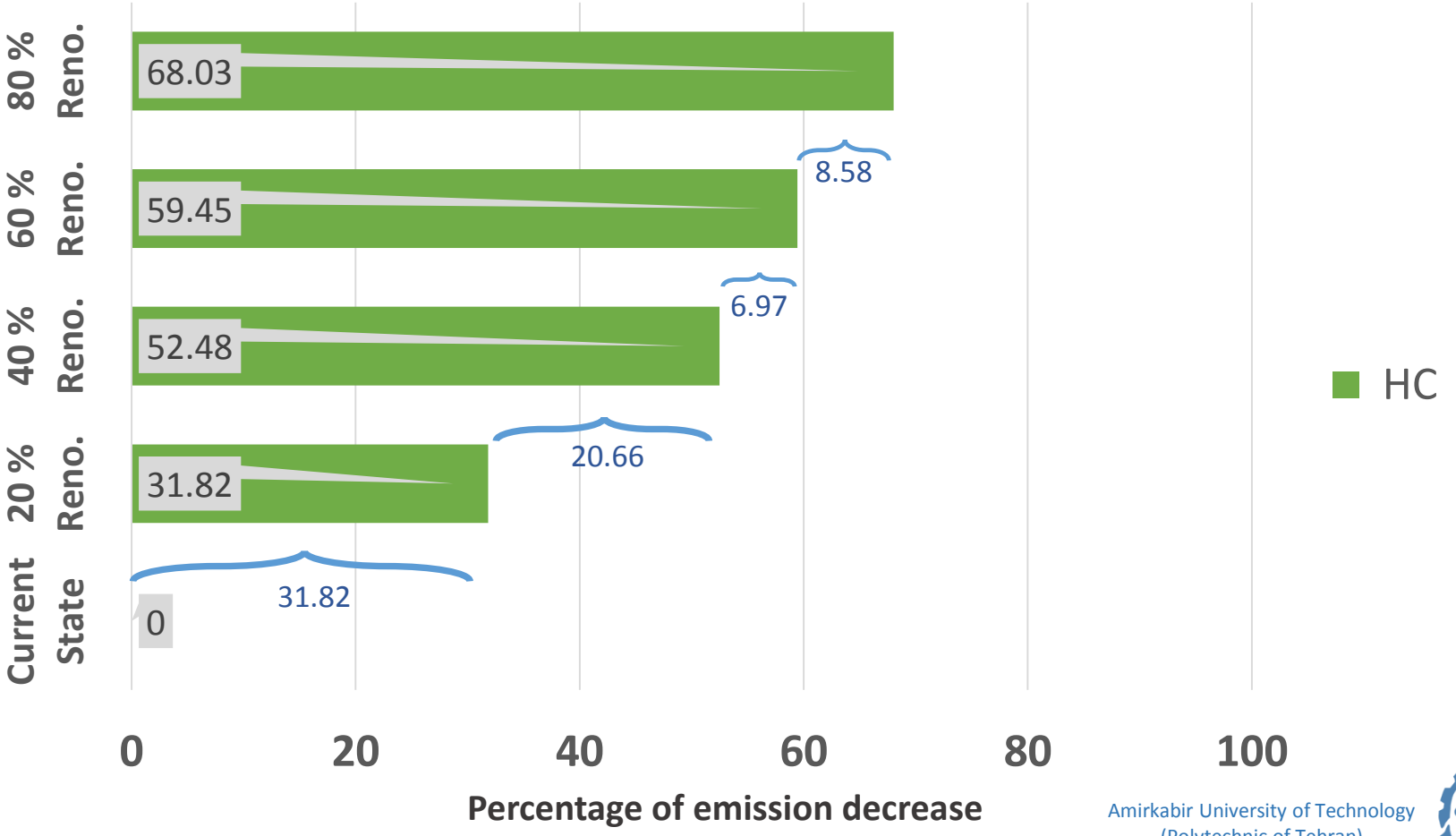
Partial changes between Renovation Scenarios and their effects on emission



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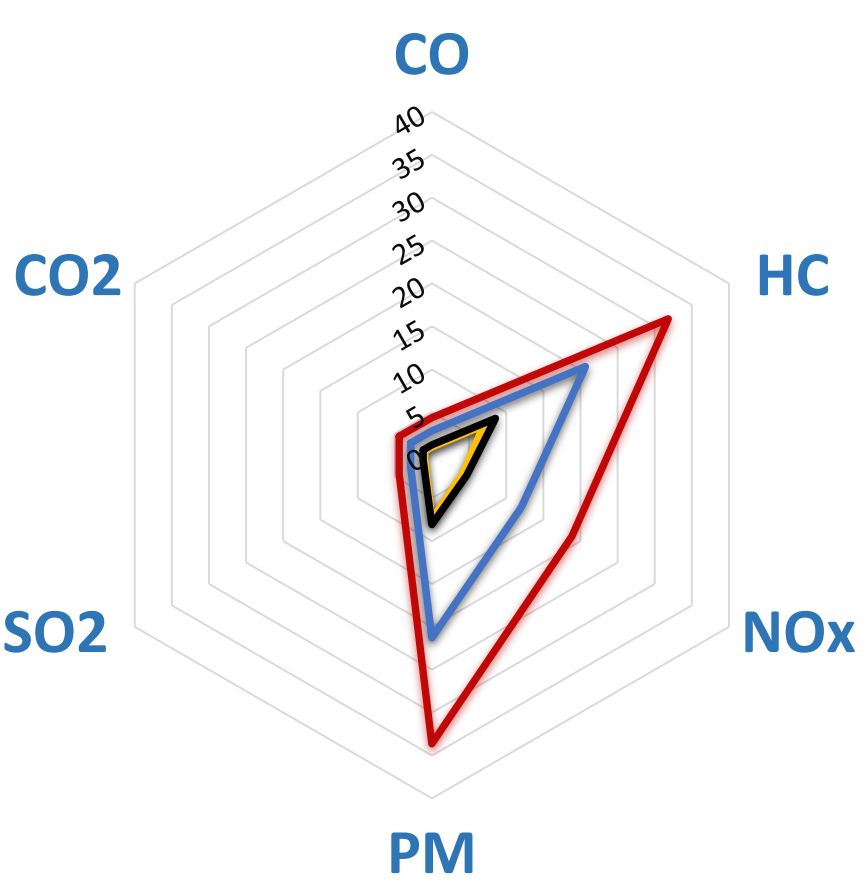
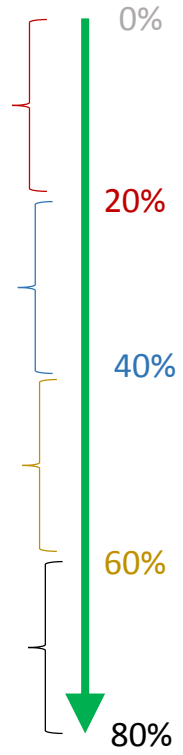


- Percentage change of emission between 0-20 % of loc. Renovation
- Percentage change of emission between 20-40 % of loc. renovation
- Percentage change of emission between 40-60 % of loc. renovation.
- Percentage change of emission between 60-80 % of loc. renovation



Benefits and Costs of RAI fleet renovation

- Benefits:
  - Reduction of emissions
  - Reduction of fuel consumption
- Costs:
  - Purchasing new locomotives
- Other benefits:
  - Reduction of maintenance costs
  - Selling old locomotives (salvage value)
  - Salvage value of new locomotives (end of lifespan)

The Cost of pollutant emission

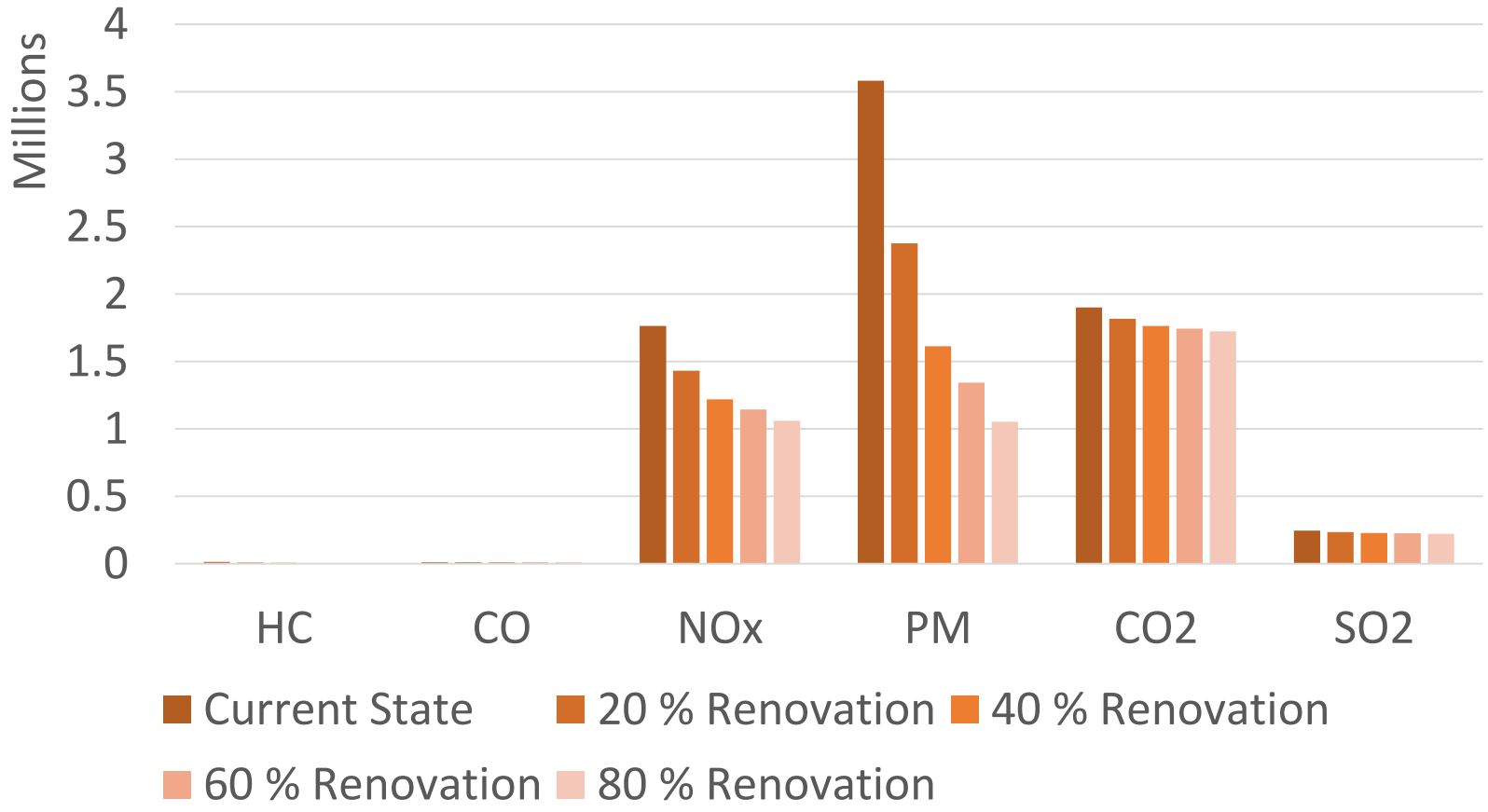
Pollutant	Cost (Euro per ton)
CO_2	13.33
SO_2	220.69
PM	9778.84
NO_x	190
CO	10.43
HC	30.3

Source: Romilly, P. (1999). Substitution of bus for car travel in urban Britain: an economic evaluation of bus and car exhaust emission and other costs. Transportation Research Part D: Transport and Environment, 4(2), 109-125.

Annual Cost of RAI emission

Scenarios	Annual cost of emission (USD)						
	HC	CO	NOx	PM	CO2	SO2	All pollutants (**M USD**)
Current State	13980.67	12833.3	1764397	3581744	1900631	245946.2	**6.545**
20 % Renovation	9532.408	12273.32	1431390	2376861	1817364	235171.1	**5.120**
40 % Renovation	6643.013	11909.58	1218823	1613799	1763476	228198	**4.215**
60 % Renovation	5669.731	11787.05	1144673	1343431	1745188	225831.5	**3.896**
80 % Renovation	4470.145	11636.04	1061578	1053619	1723091	222972.1	**3.549**

Annual Cost of RAI emission (M USD)



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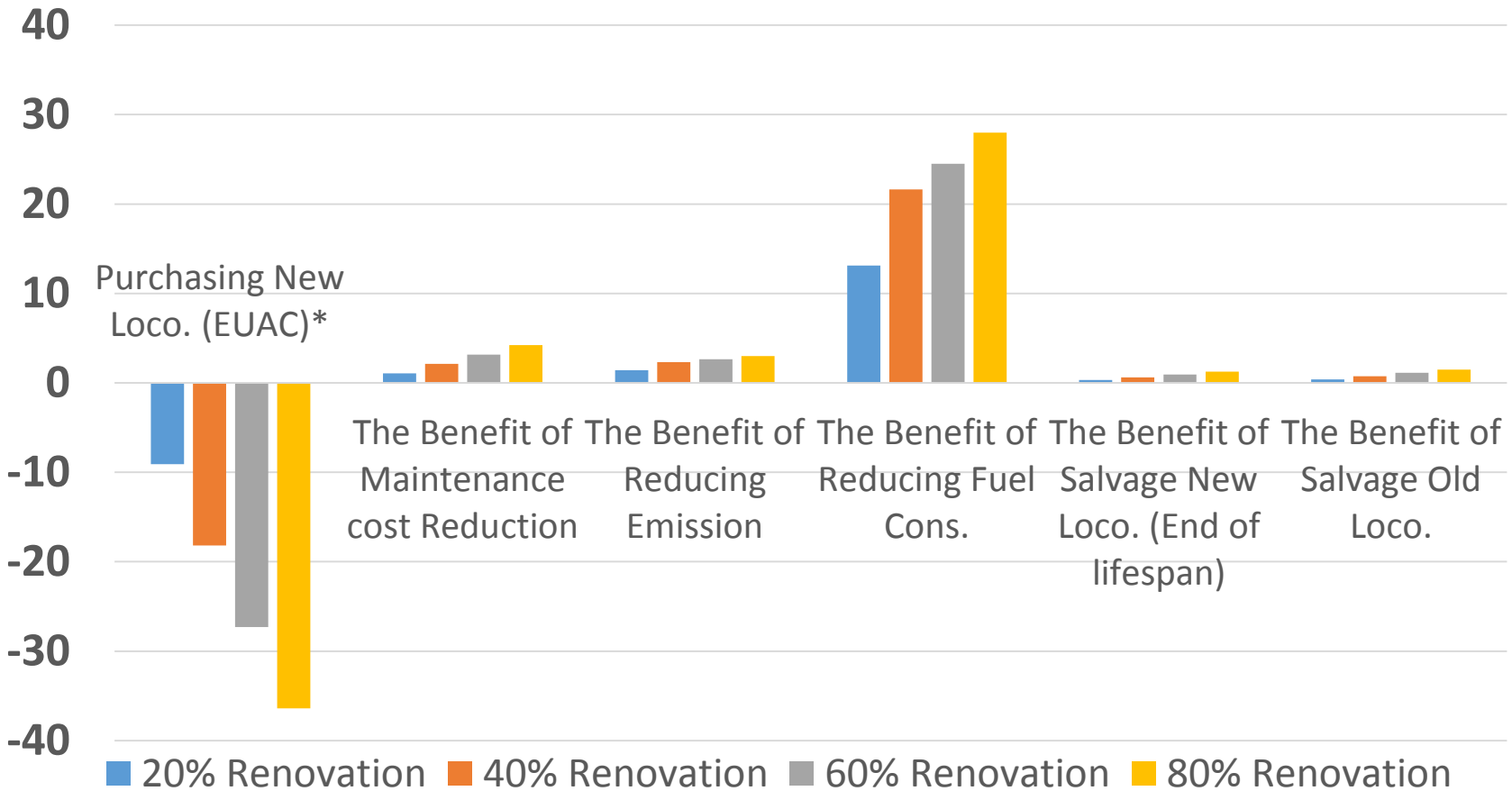
New Locomotives for Renovation of RAI Fleet

- Freight Locomotive BB 475000.
  - Year 2006 – 2015
  - Diesel engine rating: 2,000 KW
  - Starting tractive effort: 250 KN
  - Maximum speed:120 Km/h
  - Weight: 84 t
  - Track gauge: 1,435 mm
  - Price: 1.4 M USD
- Universal Locomotive Rh 2016
  - Year 2004
  - Diesel engine rating: 2,000 KW
  - Starting tractive effort: 235 KN
  - Maximum speed:140 Km/h
  - Weight: 80 t
  - Track gauge: 1,435 mm
  - Price: 1.5 M USD

The Benefits and Costs of Renovation Scenarios

Scenarios	Number of New Loco.	Costs of Purchasing New Loco. (M USD)	Annual Benefit of Reducing Maintenance Costs (M USD)	Annual Benefit of Reducing Emission (M USD)	Annual Benefits of Reducing Fuel Cons. (M USD)	The Benefit of Salvage Old Loco. (M USD)	The Benefit of Salvage New Loco. (M USD)
Current State	0	0	0	0	0	0	0
20 % Renovation	88	128	1.1	1.42	13	5.3	4.4
40 % Renovation	176	256	2.1	2.33	22	11	8.8
60 % Renovation	264	385	3.2	2.65	25	16	13
80 % Renovation	352	513	4.2	3	28	21	18

The Benefits and Costs of Renovation Scs. (M USD)



Description: All costs and benefits are converted to equivalent uniform annual benefit/cost

*EUAC: Equivalent Uniform Annual Cost

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Results of Cost-benefit analysis

Scenarios	Name	Effective annual interest rate	Economic lifespan (year)	B/C	Status
Current State	**Sc0**	0.05	25	-	-
20 % Renovation	**Sc1**	0.05	25	1.790	Accept
40 % Renovation	**Sc2**	0.05	25	1.507	Accept
60 % Renovation	**Sc3**	0.05	25	1.186	Accept
80 % Renovation	**Sc4**	0.05	25	1.042	Accept

Comparison between Scenarios

Comparison between Sc.	Delta B/ Delta C *	Superior Scenario	Selected Scenario
Sc1-Sc2	1.22	Sc2	**Sc2 (40 % Renovation)**
Sc1-Sc3	0.88	Sc1	
Sc1-Sc4	0.79	Sc1	
Sc2-Sc3	0.54	Sc2	
Sc2-Sc4	0.58	Sc2	
Sc3-Sc4	0.61	Sc3	

***Description:**

$\frac{\Delta B}{\Delta C} \geq 1 \Rightarrow$ The scenario with the higher cost is preferred

$\frac{\Delta B}{\Delta C} < 1 \Rightarrow$ The scenario with the lower cost is preferred

Conclusion

- This study has shown that annual emission of CO, NO_x, HC, PM, and SO_2 cause by RAI activity is estimated at 12500 ton and amount of CO_2 emission is 142500 ton
- Renovation scenarios have the most effect on PM, HC, and NOx emission.
- Among 4 renovation scenarios, the most decrease of emission is related to 0 to 20 % and 20 to 40% renovation. The partial change of 40 to 60% and 60 to 80% have the least effect on emission.
- Cost-benefit analysis has shown that the most efficient scenario is 40 % renovation of RAI fleet.

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