HVAC ENERGY FEEDING BY PHOTOVOLTAIC AND SOLAR THERMAL SYSTEMS IN URBAN AREA BASED ON HETEREDOX APPROACH IN ECONOMICS: A CASE STYDY OF CITY OF BELGRADE

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I. Introduction

- The production of electrical energy in Serbia predominantly relies on thermal power plants (TPPs) burning lignite
- Electrical energy obtained from TPPs in Serbia is much cheaper and more affordable than energy obtained from RES
- External costs due to pollution is not included in the price of electricity obtained from TPPs
- The aim of this paper: to investigate the effects of the mass use of PV systems and solar thermal collectors in power distribution area of city of Belgrade
- We applied social cost-benefit analysis (heterodox approach) which introduces shadow prices associated to pollution caused by TPPs

2 Methodology and Calculations

2.1 The effects of energy production from solar power systems on energy consumption from conventional sources

- The structure of Serbian electric power system: 57% of TPPs, 38% of HPPs, and 5% of RES
- With present dynamic of exploitation, Serbian reserves of lignite are limited to 50 years
- Emission of pollutant gases from TPPs: 29 million tons of CO2, 58000 tons of SO2, and 264000 tons of NOx
- Households are the biggest consumer with over 53% of total electric power comsuption
- By installing PV systems some of the consumption will be supplied from renewable sources
- Electrical energy is widely used for heating, the introduction of solar thermal collectors has the effect of reducing electricity consumption

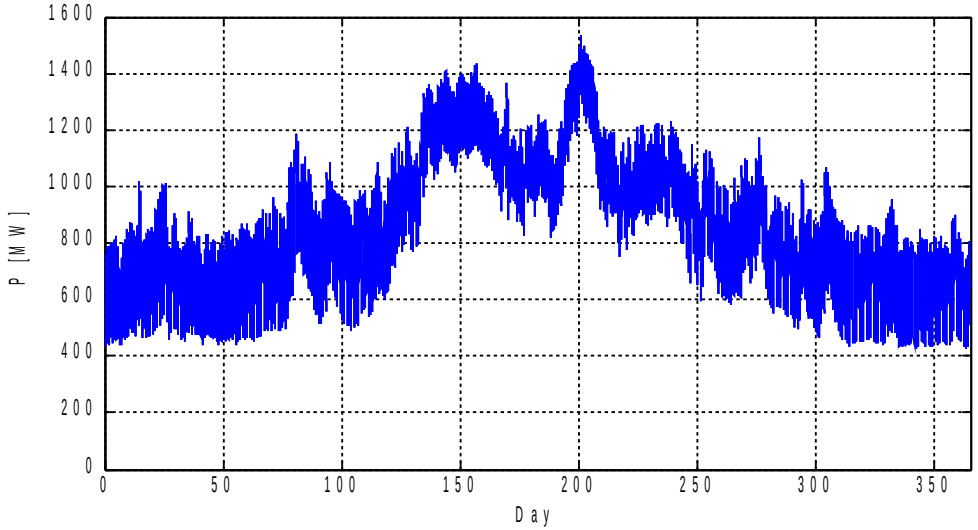

Figure 1: Power consumption diagram of Belgrade's power distribution system for the period from 15th July 2013 to 14th July 2014.

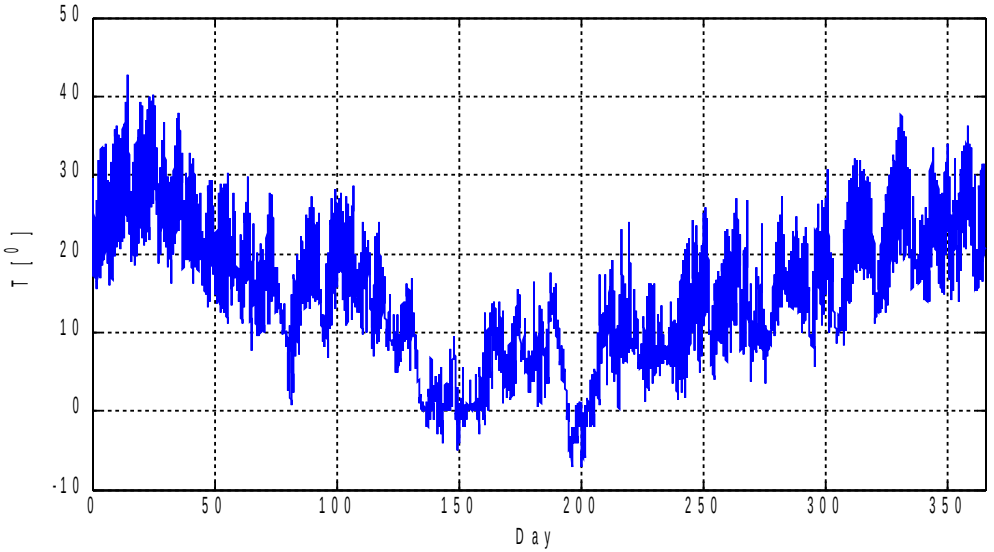

Figure 2: Ambient temperature for the period from 15th July 2013 to 14th July 2014

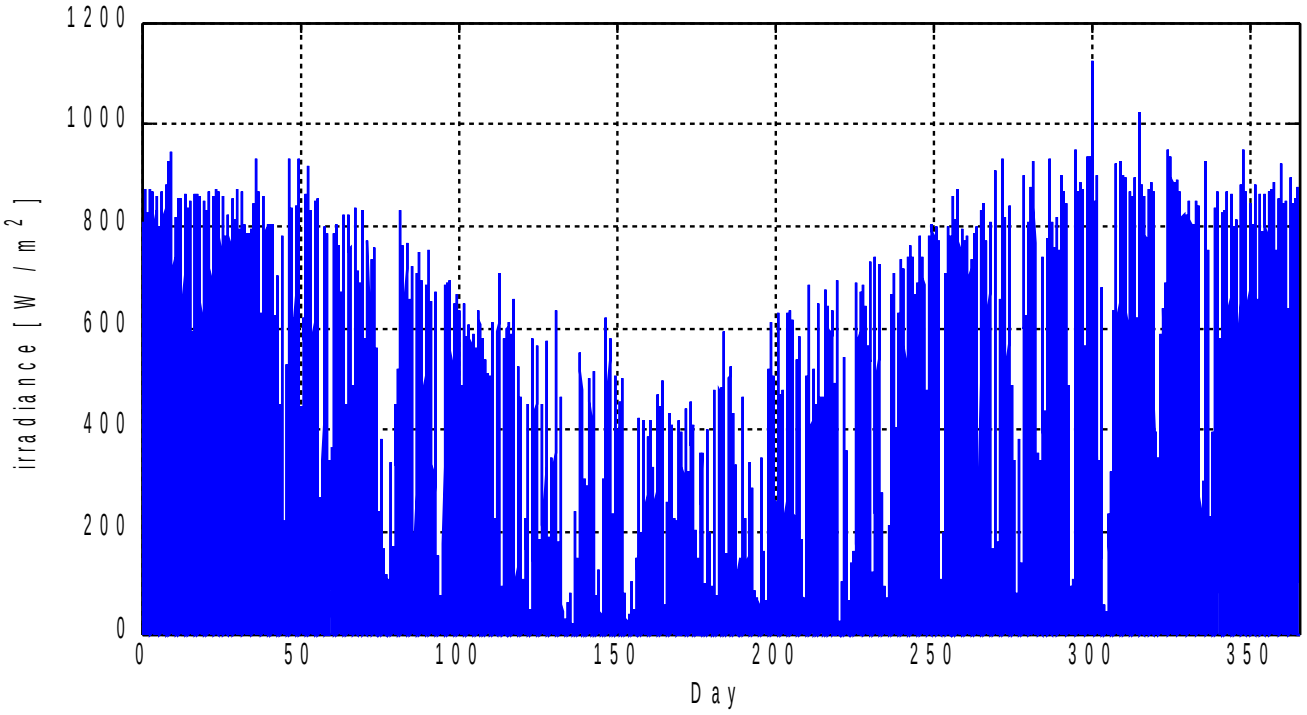

Figure 3: Irradiance on solar collector for the period from 15th July 2013 to 14th July 2014

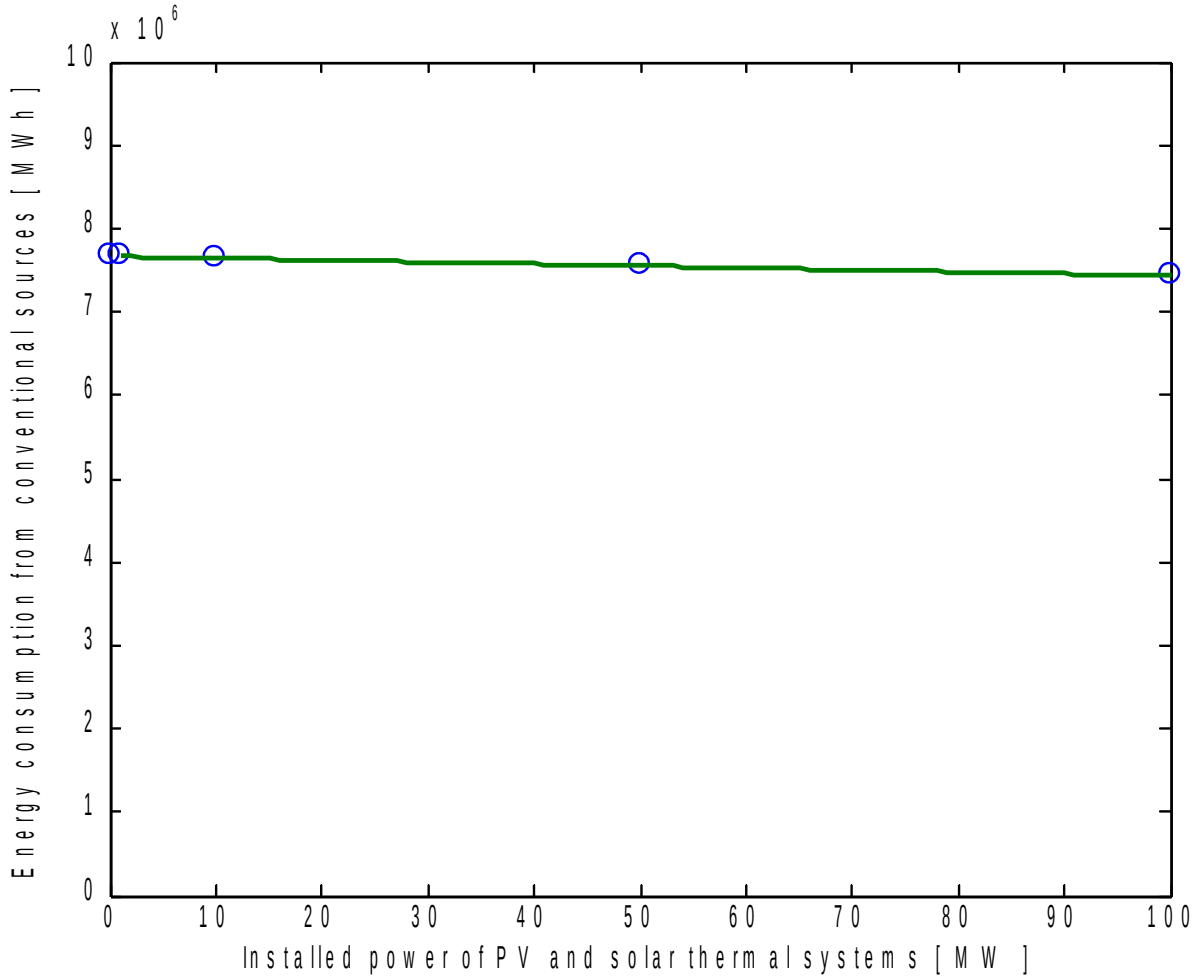

Figure 4: The effect of energy production from PV systems and solar thermal collectors on energy consumption in Belgrade's electricity distribution from conventional sources

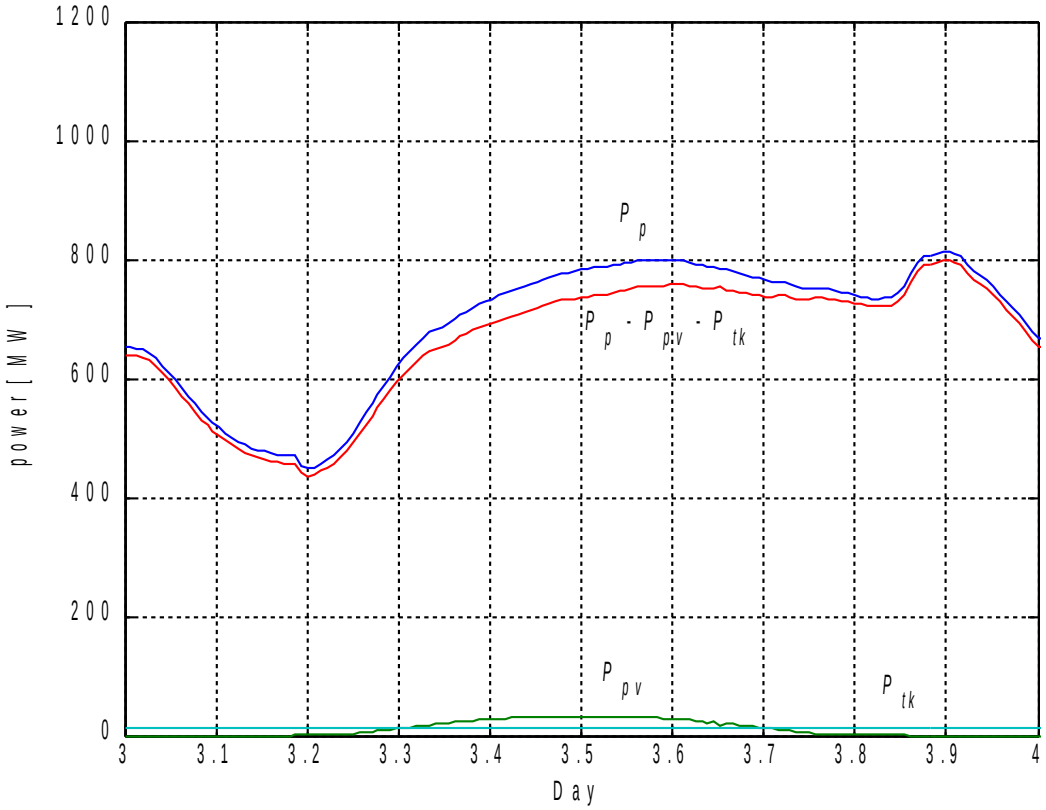

Figure 5: The effect of 50 MW generation from PV systems and solar thermal collectors on reducing electricity consumption in Belgrade's electricity distribution from conventional sources for a characteristic summer day (July 18, 2013)

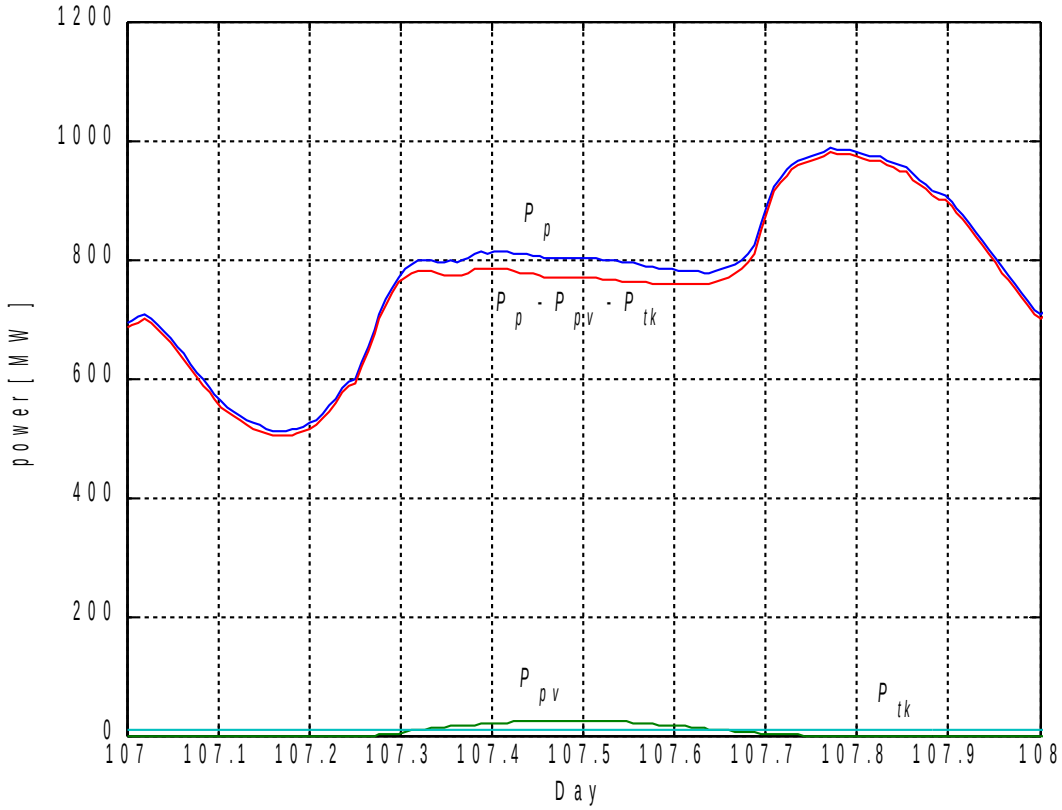

Figure 6: : Influence of 50 MW generation from photovoltaic systems and solar thermal collectors on electricity consumption in Belgrade's power distribution from conventional sources for a characteristic winter day (December 23, 2013)

2.2 The effects of energy production from solar power systems on the reduction of pollutant gases emission

- The main global negative impacts of pollutant gases: global warming, acid rains and negative impact on water quality and ecosystem

Table 1: The average emissions of pollutant gases during the production of electricity from different sources

Type of power plant	CO_2 (kg/MWh)	NO_x (kg/MWh)	SO_2 (kg/MWh)
Coal/lignite	986	2,986	16,511
Oil	1131	5,253	81,590
Natural gas	560	1,477	0,152
Nuclear	21,4	0,051	0,027
Hydro	22,7	0,023	0,033
Wind	17,7	0,032	0,054
Solar (photovoltaic)	49,2	0,178	0,257
Solar thermal collectors	39	0,038	0,2
Biomass	58	1,325	0,076

Table 2: Characterization factors for pollutant gases

Impact Categories	*Impact gas*	*Characterization factor (U)*	*Reference gas*	*Value of factor U*
global warming	CO_2	GWP (Global warming potential)	$CO_{2ekv.}$	1
	CH_4			21
	N_2O			310
acid rains	SO_2	AP (Acidification potential)	$SO_{2ekv.}$	1
	NO_X			0,7
	NH_3			1,88
	HCl			0,88
water quality and ecosystem	NO_X	EP (Eutrophication potential)	$PO_4^{3-}{}_{ekv.}$	0,13
	NH_3			0,33

- The total annual emissions of equivalent CO_2, SO_2 and PO_4^{3-} during the production of electricity in a power plant

$$MCO_{2e} = W \times (mCO_2 + GWP_{NO_x} \times mNO_x)$$

$$MSO_{2e} = W \times (mSO_2 + AP_{NO_x} \times mNO_x)$$

$$MPO_{4e}^{3-\,(SE)} = W \times EP_{NO_x} \times mNO_x$$

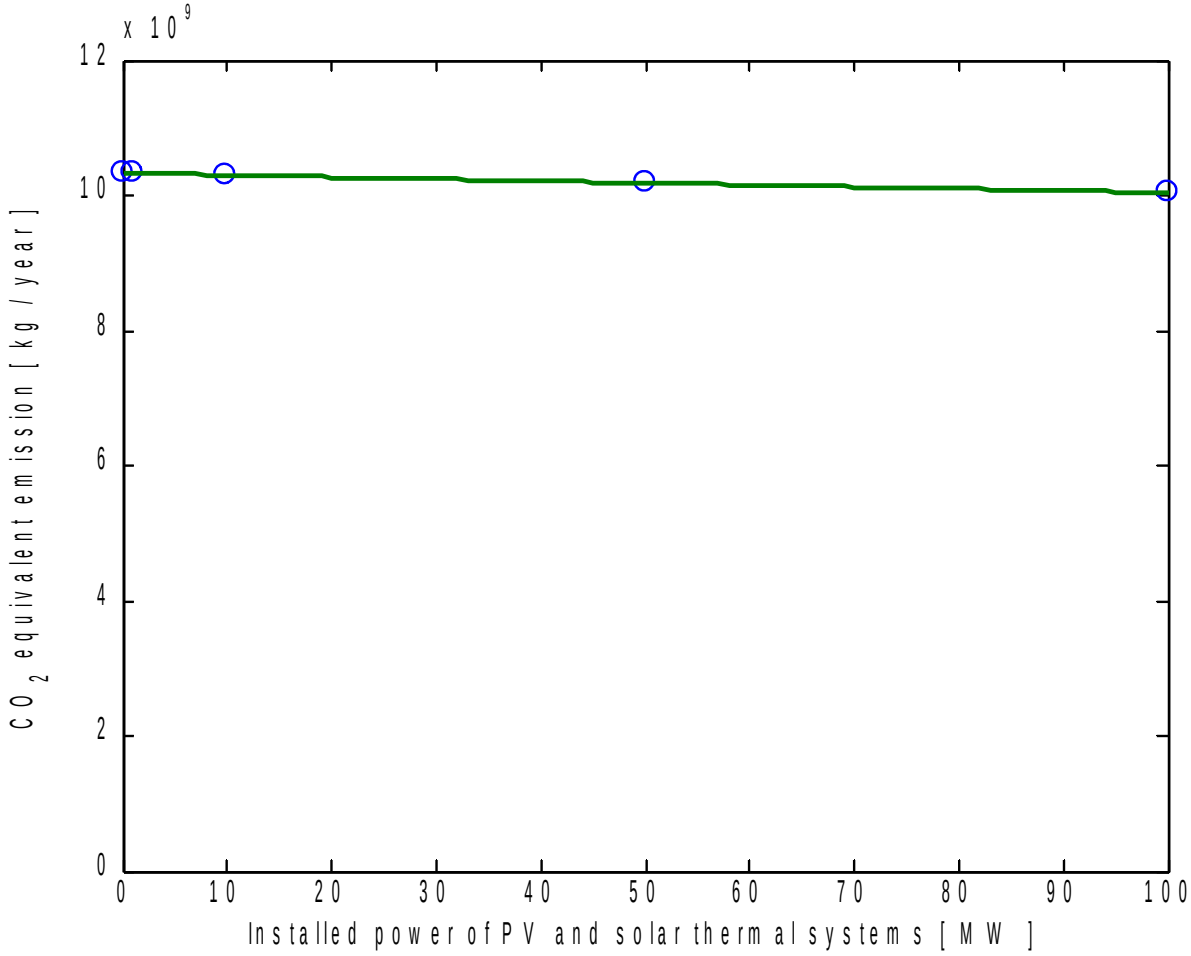

Figure 7: The influence of energy production from PV systems and solar thermal collectors on reducing CO_2 equivalent emission

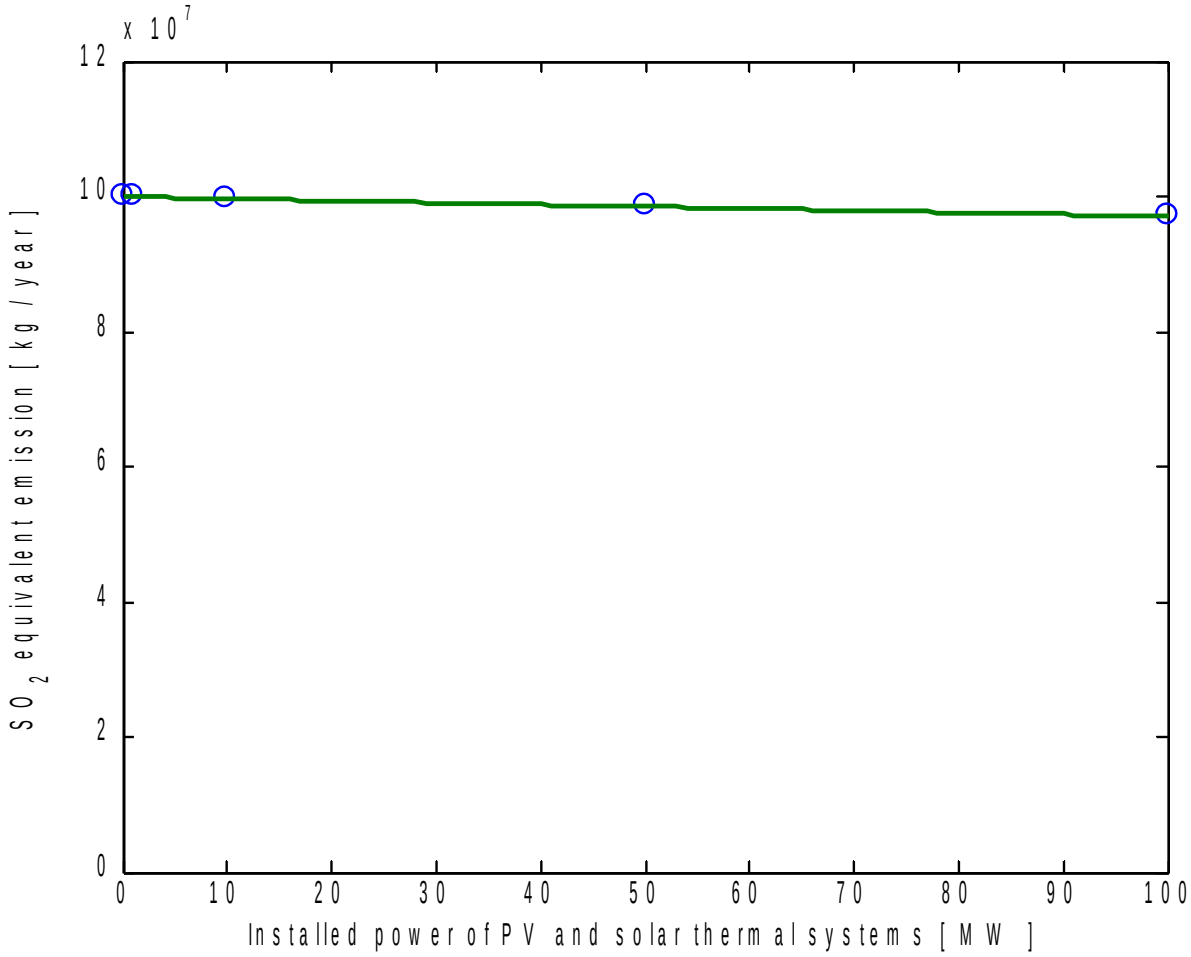

Figure 8: The influence of energy production from PV systems and solar thermal collectors on reducing SO_2 equivalent emission

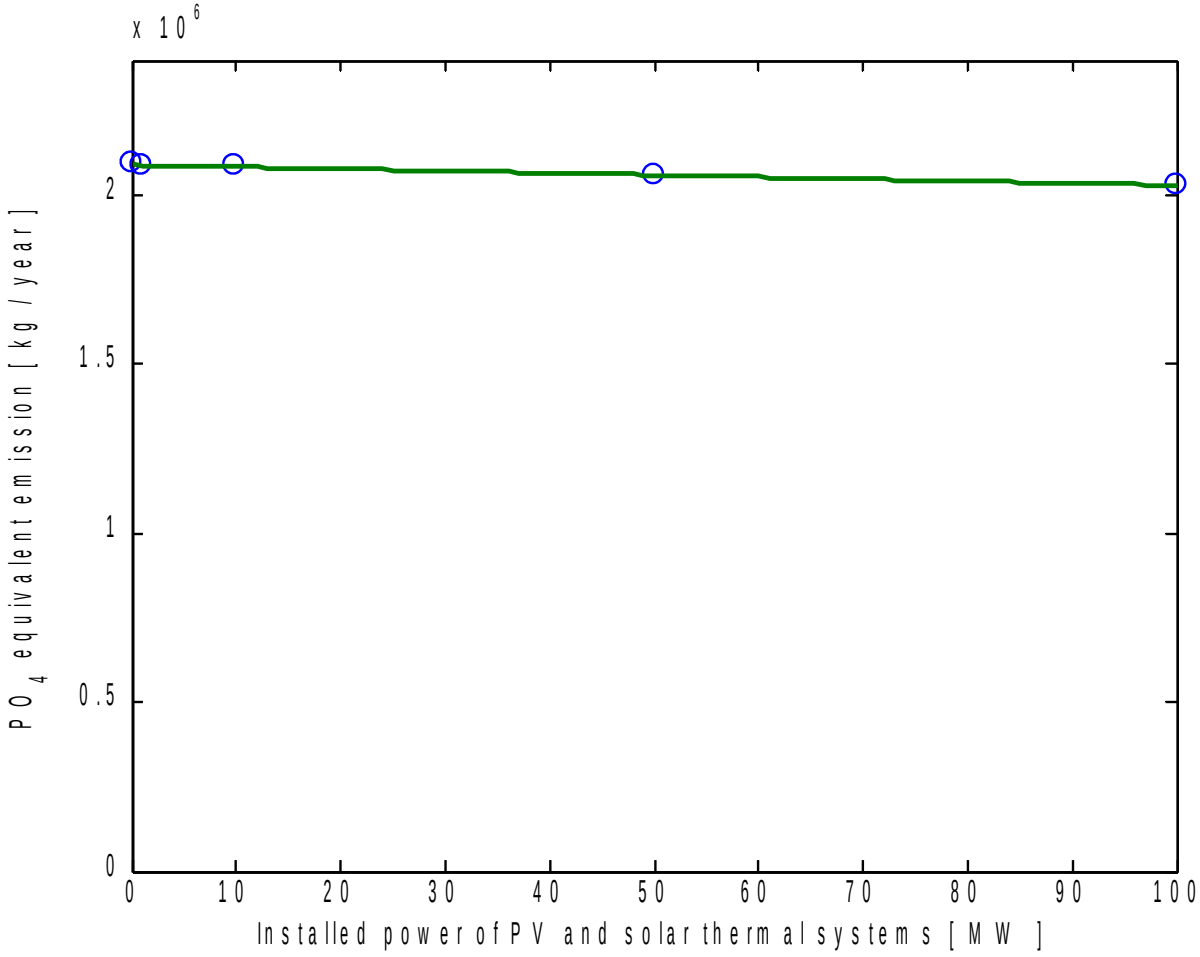

Figure 9: The influence of energy production from PV systems and solar thermal collectors on reducing PO_4^{3-} equivalent emission

2.4 Prices of energy obtained from solar power systems

- Levelized cost of energy (LCOE) is the average cost of energy per kilowatt-hour

$$LCOE = \frac{C_I(0) + \sum_{k=1}^{n} \frac{C_I(k) + C_M(k) + C_F(k)}{(1+d)^k}}{\sum_{k=1}^{n} \frac{W(k)}{(1+d)^k}}$$

- LCOE for PV systems installed on the roofs of buildings and houses:

  $C_{\text{PV small}}$=114.4 €/MWh=11.44 c€/kWh
- LCOE for large PV systems installed on the ground:

  $C_{\text{PV large}}$=91.15 €/MWh=9.15 c€/kWh
- The feed-in tariffs for PV systems in the Republic of Serbia:

  $C_{\text{PV small}}$=11.72 c€/kWh

  $C_{\text{PV large}}$=9 c€/kWh
- LCOE for solar thermal systems:

  $C_{\text{PV small}}$=75.3 €/MWh=7.53 c€/kWh

3 Results and disussion

- LCOE for lignite TPPs in South-Eastern Europe, excluding CO_2 certification prices (according to IRENA):

  from 4.7 c€/kWh to 6.4 c€/kWh

- The full price of energy obtained by TPPs should include **levelized cost of pollution (LCOP):**

$$LCOP = \frac{\sum_{k=1}^{n} \frac{C_e \cdot 1.035^{k-1} \cdot \Delta e}{(1+d)^k}}{\sum_{k=1}^{n} \frac{W(k)}{(1+d)^k}}$$

where C_e is the cost of emission growing at a rate of 3.5% each year.

- Yearly emissions of pollutant gasses from Serbian TPPs are:

  $\Delta e_{CO2} = 1.03 \cdot 10^{10}$ kg/year

  $\Delta e_{SO2} = 9.99 \cdot 10^{7}$ kg/year

  $\Delta e_{PO4} = 2.90 \cdot 10^{6}$ kg/year

Table 3: Cost of emission €/kg according to EU Commission for social cost-benefit analyses

Gas	Lower estimate (€/kg)	Central estimate (€/kg)	High estimate (€/kg)
CO_2	0.022	0.057	0.094
SO_2	8.3	11.5	17.9
PO_4	0.0876	0.159	0.226

- Levelized cost of pollution (LCOP) for Serbian TPPs are:

  4.04 c€/kWh for CO_2

  14.75 c€/kWh for SO_2

  0.33 c€/kWh for PO_4

- The full price of electrical energy produced by TPPs in Serbia is:

  (4.7+4.04+14.75+0.33) c€/kWh = 23.8 c€/kWh

4 Conclusions

- Conventional energy obtained predominately from lignite is more affordable due to high initial investment costs of solar power systems
- However, a social responsible economic model shows that solar energy is cheaper because of the extraordinarily high cost that pollution poses on society