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A Critical Approach for Energy Conservation in Irrigation Systems by Optimal Sizing of Pumps

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Abstract*— This paper presents achievement of energy conservation in irrigation systems by optimally sizing the pump and PVC pipe network. The proposed sizing technique employs irrigation water need, hydraulic head and pump operating hours with an optimal water flow at 1.5m/s. Based on crop water requirement and available operating hours, diameter of pipe and flow rate are assessed. The physical conditions of the agri-land are used utterly to determine hydraulic head. Pump capacity to discharge necessary water over the defined head at best efficiency is obtained from the hydraulic power equation of the pump. The presented method is employed to identify energy conservation potential at Malaprabha river bed, Karnataka, India. A critical survey of agri-lands is taken up and optimal sizes are suggested. It is found that, in a span of 1.5 km riverbed, approximately 40% of installations are in excess. Further, energy conserved, cost savings and possible reduction in CO2 emissions are determined. It is concluded that proposed method at larger scale, will achieve energy conservation in irrigation loads and drastically reduce burden on power grid without affecting the water supply reliability.

***Index Terms*— Energy Conservation, Irrigation systems, Suction and Discharge head losses, Centrifugal pumps, Crop water**

I. NOMENCLATURE

ET_{crop}	Crop water requirement (mm/day)
ET_o	Reference crop evapotranspiration (mm/day)
P	Mean daily percentage of annual day time hours
T_{mean}	Mean daily temperature (°C)
T_{max}	Average of maximum temperatures in month (°C)
T_{min}	Average of minimum temperatures in month (°C)
Q	Water flowrate (m^3/s or lit/hour)
V	Velocity of water flow in PVC pipes (m/s)
A	Cross sectional area of pipe (m^2)
d	Diameter of pipe (m)
l	Length of the pipe (m)
V_{be}	Velocity before expansion (m/s)
V_{ac}	Velocity after contraction (m/s)
h_f	Head lost due to friction (m)
h_e	Head lost due to diameter expansion (m)
h_c	Head lost due to diameter contraction (m)
h_b	Head lost due to bends (m)
h_{fi}	Head lost due to foot Valve and fittings (m)
H	Total hydraulic head (m)
η	Efficiency of the pump (%)
ρ	Density of water in (kg/m^2)
g	Acceleration due to gravity (m/s^2)
E_c	Energy conserved per day (kWh)
P_{ic}	Installed capacity in the field (hp or Watts)
P_{ac}	Assessed pump capacity (hp or Watts)
T_i	Operating hours of installed pump (Hours)

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II. INTRODUCTION

India is a country with more than six lakh villages and 70% of population is involved in agriculture and associated activities. Agriculture is the backbone of Indian economy and contributes a major part in GDP. Farmers entirely dependent on variable rainfall and groundwater to fulfill irrigation need of the crops. It is estimated that, government subsidizes electricity for irrigation between Rs.30000 and 40000 corers each year. There are an estimated 21 million irrigation pumps in India out of which 12 million are on the electricity grid. Electricity consumption by irrigation pumpsets alone accounts between 20-25% of India's total electricity consumption, which has become burden on grid. Building further generating units and grid system, is too expensive. This created difficulty in load management and lead to load shedding. On other hand, to serve required crop water within available time, farmers install excessive pump capacities and multiple pumps. This will cascade the excessive demand on the electric grid. This issue can be resolved by identifying the excessive installations and re-sizing them optimally. The optimized irrigation load will reduce burden on grid, achieve energy conservation and reduce the CO_2 emissions [1]. Dr.Bansal had described the methodology to select rating of irrigation pumps. Sizing is carried based on discharge and head offered. The detailed methodology to assess the major and minor head losses is presented [2].

Dr.Guy Fipps discussed the assessment of hydraulic head and optimal irrigation pump rating. It is shown that for sustained operation, velocity of water in PVC pipes must be 5 foot/sec i.e. 1.52m/s. Further, potential damage to pipe network due to higher velocity is discussed [3]. Mathew Milnes presented assessment and significant causes of minor losses. Inference about improper sizing of pumps is discussed. It is proved that oversized pump results in excess water and undersized pump results in inadequate water output [4]. Literatures discussed the issues associated with design of irrigation pumps. The previous optimizing techniques of pumping systems, which have been the subject

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of numerous papers, mainly dealt with improvement of effectiveness of various system components, as well as their better mutual adjustment, with the aim of total cost reduction of the pumping system. However, re-sizing the pumps based on the exact crop water need for achievement of energy conservation has never been the topic of interest. The current scenario in Indian agricultural lands has a great deal of energy saving opportunities. In this regard, a critical method for sizing irrigation pumps based on exact water need and land structure is proposed. The proposed concept is employed in selected agriculture fields at Malaprabha riverbed, Karnataka, India, to assess the saving potential.

III. METHODOLOGY

The proposed method yield the optimal size of irrigation pump and the PVC pipe network without affecting the water supply reliability to the crops. The method incorporates crop water, local field conditions, availability of electricity supply and hydraulic head for sizing. The flowchart shown in Fig.1 presents the methodology employed in the present work.

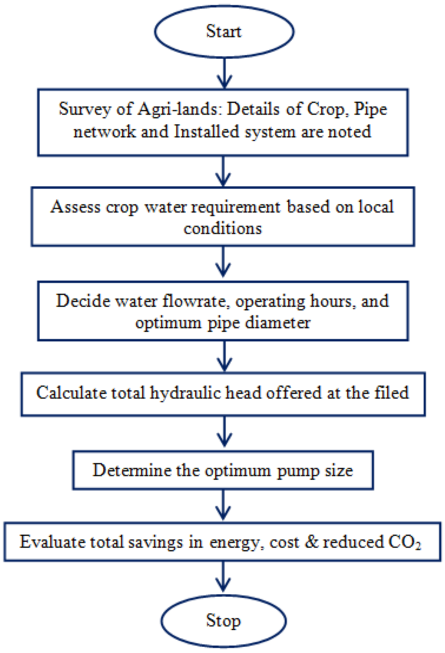

Fig.1: Flowchart representing the methodology

A. Irrigation Water Requirements of the Crops

Crop water requirement is the evapotranspiration due to environmental conditions. It depends on cultivation area, type of the soil and percolation property, season of the year, temperature, latitude of location and type of the crops grown. Thus, total crop water is assessed by evapotranspiration, which will yield optimum water need in mm/day with approximating climatic factors. The crop water requirement is given by (1) [5-6];

$$\mathrm{ET}_{crop} = K_C \times ET_o \quad mm/day \tag{1}$$

Reference crop evapotranspiration (ET_0) depends on the local conditions of selected site and hence ET_0 is assessed by mean daily temperature data using Blaney-Criddle method for selected site. The assessment of ET0 is presented by (2);

$$\mathrm{ET}_0 = p(0.46T_{mean} + 8) \quad mm/day \tag{2}$$

$$T_{mean} = \frac{T_{\max} + T_{\min}}{2} \quad °C \tag{3}$$

Mean daily percentage of annual day time hours (p) varies from 0.24 to 0.30 throughout the year in the southern part of India. Crop factor (K_c) presents water requirement (ET_{crop}) of particular crop at varying growth stages. Four growth stages of crops are distinguished: initial stage, crop development stage, mid-season stage, late season stage. Major water consumption will be during mid-season stage. However, the length of the different crop stages will vary according to climatic conditions. With known values of crop factors and growth period, water requirements can be calculated for various crops. In the present methodology, sizing of the pumps is carried for maximum water requirement conditions i.e for the mid-season stage of any crop. Thus, the resulting pump will fit for all seasons and worst conditions. For the site at Malaprabha Riverbed (15.8351N-75.5394E), Karnataka, reference crop evapotranspiration were assessed for different months. It is observed that maximum value of ET_0 is 6.20 mm/day. Further, crop water requirements for various crops for the selected site are evaluated. Table.1 presents the crops and water requirements of major crops grown in selected site.

Table.1.Crop factors at Mid-season stage & corresponding water requirements of major crops grown in North-Karnataka, India [5-6]

Crop	Crop Factor (K_c)	Crop Water (mm/ day)	Crop Water (m^3/Acre/ day)	Crop Water (lit/Hect./ day)
Sugarcane-SG	1.15	7.13	28.8	71300
Cotton-CT	1.15	7.13	28.8	71300
Sorghum-SR	1.10	6.82	27.59	68200
Tomato-TM	1.15	7.13	28.8	71300
Onion-ON	1.00	6.20	25.08	62000
Maize-MZ	1.15	7.13	28.8	71300
Sunflower-SF	1.10	6.82	27.59	68200
Groundnut-GN	1.00	6.20	25.08	62000

B. Assessment of Flowrate and Diameter of PVC Pipe Network

Water flowrate is the amount of water discharged from the pump per second. Total water required per day has to be supplied within the span of electricity supply hours. Karnataka state government assures six hours of three phase quality power for irrigation purpose. To size pump optimally, water flowrate in liters/hour is accurately assessed based on supply hours. Required flowrate is given by (3);

$$Flowrate(Q) = \frac{Total\ water\ required\ per\ day\ in\ liters}{No.of\ hours\ of\ electricity} \quad lit/hour \tag{4}$$

Further, diameter of the pipe network is selected for water flow velocity of 1.5 m/s. For sustained operation without wear and tear and to prevent water hammer effect, velocity of water in PVC pipes is limited to 5-6 feet/sec i.e. 1.524 m/s. Water flowrate in m3/s in terms of velocity and pipe area is given by (4). Further, diameter of pipe with flowrate in lit/hour is assessed by (5);

$$Q_{Cubicmtr} = V \times A \quad m^3/S \tag{4}$$

$$d = \sqrt{Q_{lit/hr} / (4.248 \times 10^6)} \quad mm \tag{5}$$

C.Assessment of Hydraulic Head Offered to Pump

As water flows through pipe, it experiences resistance due to which part of the energy gets lost. Losses developed on motor depend on elevation of water level to be lifted, bends, valves, friction, change in diameter and length of the pipe. Major loss of head is due to friction and is assessed from Darcy-Weisbach equation given by (6). Other losses are minor, as compared to friction and elevation. However, optimal sizing of pump necessitates them to be incorporated in the design procedure. These losses are assessed by (7)-(11). Major and minor losses together referred as dynamic head. Elevations at suction and discharge sides are termed as static head. Static head at suction side is variable in small reservoirs. On other hand, this head remain constant in riverbed pumps. Thus, total head offered to pump is sum of dynamic and static heads. This is presented by (12).

A. Assessment of Hydraulic Head Offered to Pump

Head lost due to friction,	$h_f = \frac{4flV^2}{2gd} \quad m$	(6)
Head lost due to expansion,	$h_e = \frac{(V_{be} - V_{ae})^2}{2g} \quad m$	(7)
Head lost due to contraction,	$h_c = \frac{KV_{ac}^2}{2g} \quad m$	(8)
Head lost due to 90° bend,	$h_b = 0.45\frac{V^2}{g} \quad m$	(9)
Head lost due to 45°bend,	$h_b = 0.25\frac{V^2}{g} \quad m$	(10)
Head lost due to foot Valve,	$h_{fi} = 0.75\frac{V^2}{g} \quad m$	(11)
Total Head(H),	$H = H_{static} + H_{dynamic} \quad m$	(12)

D. Assessment of Pump Rating

HP rating of the pump is power required to lift water with desired flowrate against total head at the field. Pump capacity is assessed by hydraulic power equation, given by (13).

$$P_{in} = \frac{\rho \times g \times Q_{Cubicmtr} \times H}{\eta} \quad W \qquad 13)$$

The pump rating is assessed at Best Efficiency Point (BEP), 70%. Cross verification is carried with selected diameter, pump rating in the performance sheet. The combination of power rating, head and flowrate must in line with best efficient condition of the pump. For given pump rating, optimum combinations of flowrate and head can be selected from manufacture data sheet. It is observed that an increased diameter of discharge terminal handles larger heads, for the same power rating.

E. Energy Conservation, Cost Savings and CO2 Reduction

Sizing is carried for six hours of operation per day. In practice, farmers operate the irrigation pumps during three phase supply for minimum six hours and against law, few more hours, using the condensers in one of the phases. This will create drastic change in the energy consumption pattern of the installed capacities with newly assessed pump ratings. Energy conserved per day by assessed pump over installed pump is given by (14). As the sizing is carried for mid-season stage of the crops, energy consumption during other periods will be much lower.

$$E_c = 0.745[(P_{ic} \times T_i) - (P_{ac} \times T_{6hours})] \quad kWh \tag{14}$$

In Karnataka state, electricity is being supplied freely for farmers and don't have metering provision for consumption monitoring. In such scenario, tariff structures can't be used to evaluate cost savings. This lead for assessment of generation cost savings with reduced consumption. With standard generation cost of 1.9 Rs/kWh is employed for analysis. Cost savings in the generation side by assessed pump per day during the mid-season stage is given by (15) [7].

$$Cost\ Savings = E_c \times Cost\ per\ kWh \quad Rs. \tag{15}$$

The reduced CO_2 emissions are determined by standard emission protocol of India for CO_2 emissions per kWh generation. It is estimated that, each unit of generation in India accounts for 0.909 kg of CO_2 [8]. Thus, reduction in emissions per day during mid-season stage is assesses by (16).

$$CO_2\ emissions\ reduced = E_c \times 0.909 \quad kg. \tag{16}$$

IV. RESULTS AND DISCUSSIONS

A. Survey carried at Malaprabha riverbed

A critical survey is conducted with farmers and details of agriculture land and pumping units are collected. Installed pump capacity, length and diameter, fittings and bends in pipe network, crops grown, size of land, number of gaps in irrigation and number of hours of pump operation are noted. Walkthrough survey revealed that most of the installed ratings are oversized. Further, based on their water need and field conditions optimal pump rating is suggested for each case. The results depict the large energy conservation opportunity in irrigation systems for selected 30 agriculture lands. Existing total capacity of 250 Hp is optimally brought down to 129 Hp without affecting the water supply quantity.

The systems are designed for peak water requirement conditions i.e for the mid-session stage of the sugarcane crop. Thus the identified rating will be sufficient for all seasonal conditions. From 30 cases 121 Hp (48.4%) excessive installations are identified, resulting in 540 kWh

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units of energy conservation per day, savings in generation cost of Rs.1027 per day and reducing the CO_2 emissions by 491 Kg/day. Few cases are identified, where lesser capacity is installed and crops running short of water. However, in total for 50 cases along 1.5km length of riverbed, 30% of excess installations are identified. With the proposed concept and sizing pumps optimally, significant energy can be saved without affecting the crop water requirements. Comparison of installed pump capacity and assessed pump capacity for 30 cases is shown in Fig.2. It is observed that most systems are oversized and are suggested with standard pump sizes of optimal capacity.

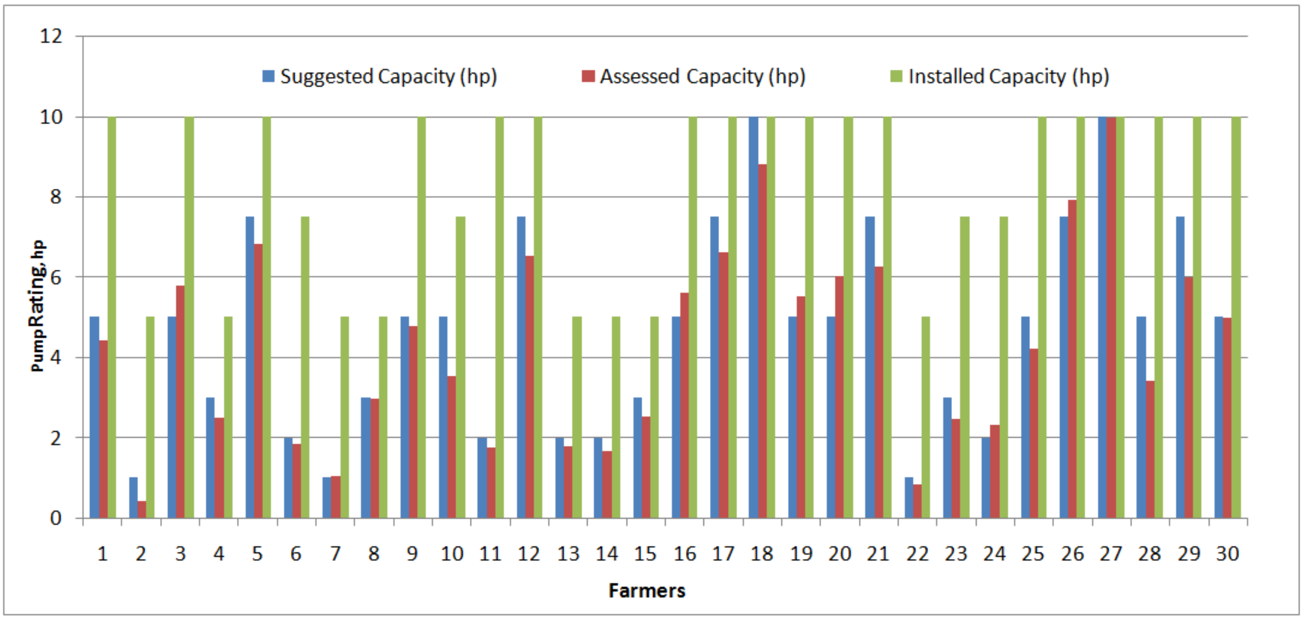

Fig.2: Comparison of Assessed and installed capacities

Fig.3 presents the comparison of energy consumed per day by existing pump capacity and optimum sized capacity with reference to excess capacity identified in each case. The assessment of energy conservation is carried for 6 hours of the electrical supply hour. Results revealed that, every installation possess the conservation potential irrespective of the installed sizes. Energy conservation increases with increase in excess capacity installations. With 1.9 Rs/kWh generation cost, the savings in cost are assessed.

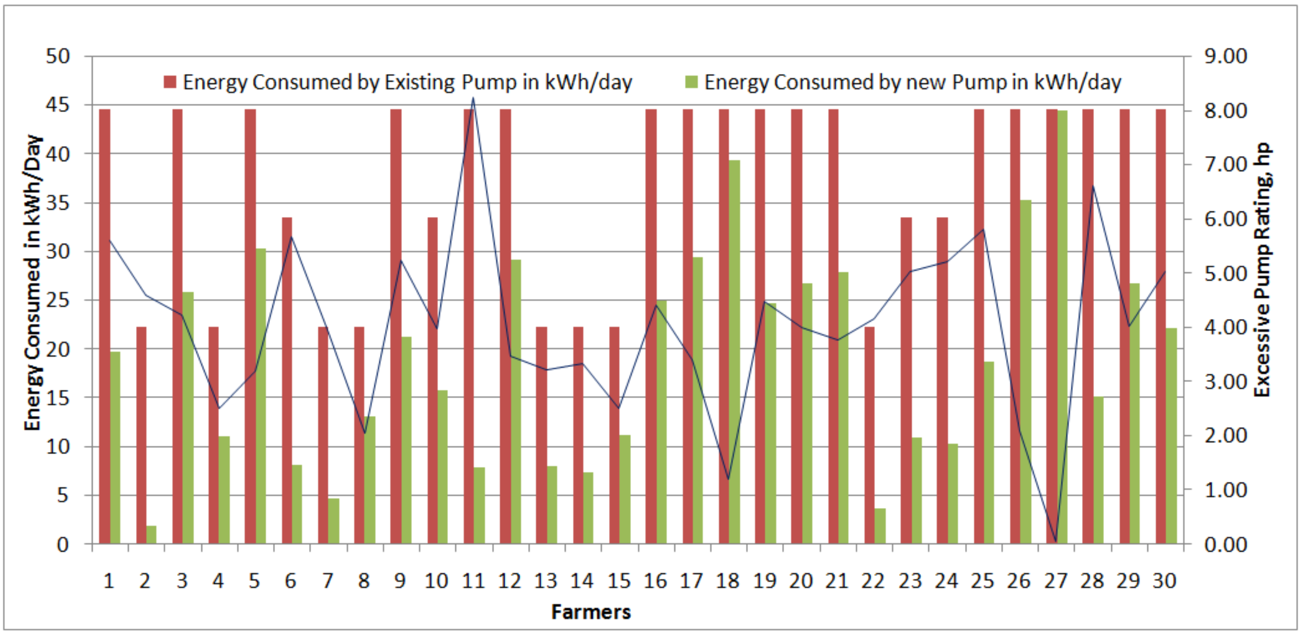

Fig.3: Comparison of energy consumed with excess pump capacities

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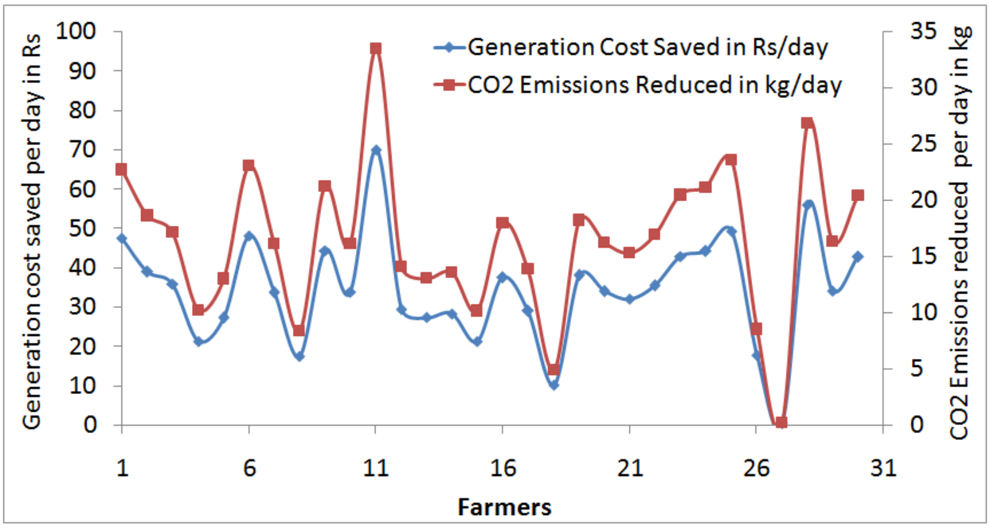

Fig.4: Comparison between cost saving and CO2 reductions

Fig.4 indicates the generation cost savings and reduction in CO_2 emissions per day. It clearly presents the outcome benefits associated with cost savings from generation and potential to mitigate the CO_2 emissions by the proposed concept of energy conservation.

V. CONCLUSIONS

Energy conservation opportunity in irrigation systems and solution is presented in the paper. Methodology for optimally sizing the pumps based on water need and local hydraulic conditions was proposed. Survey was conducted for 50 agriculture lands at Malaprabha riverbed and optimal sizing of pumps was carried for each case and suitable standard pump sizes were suggested. For 30 cases of the survey, optimal sizing of pumps indicated excess installations of 48.5%, 540 kWh of energy is conserved per day, saving Rs.1027 and reducing the CO_2 emissions by 491 kg/day. Results proved that, significant energy can be conserved by optimally sizing the pumpsets. It was concluded that, implementation of the proposed scheme in large scale, will be a boon for the energy conservation and reduces the burden on national grid.

REFERENCES

1. Pradip Narale, Prof. Narendra Singh Rathore, Solar Water Pumping System For Agriculture, Department of Renewable Energy Engineering, Maharana Pratap University of Agriculture And Technology, Udaipur (Rajasthan), Energética India, AUG 15, pg 4-5.
2. Dr.R.K.Bansal, “Fluid Mechanics and Hydraulic Machines”, Comprehensive Textbook, LAXMI Publications, Delhi, 2008.
3. Guy Fipps, “Calculating horsepower requirements and sizing irrigation supply pipelines”, Texas Agricultural Extension Service, The Texas A&M University System, Mexico, December 2010.
4. Mathew Milnes, “The mathematics of pumping water”, Department of civil Engineering, The Royal academy of Engineering, London, April 2011.
5. Dr. D.K. Subramanian and Dr. T.V. Ramachandra, “Aspects of Agriculture and Irrigation In Karnataka”, Energy Research Group, Centre For Ecological Sciences, Indian Institute of Science, Bangalore 560 012, India
6. http://www.fao.org/docrep/s2022e/s2022e07.htm (Crop water requirements, 13th April 2016)
7. Matthew Brander, AmanSood, Charlotte Wylie, Amy Haughton, Jessica Love, “Electricity-specific emission factors for grid electricity”, Ecometria, August 2011, emissionfactors.com

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