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Time value of emission and technology discounting rate for off-grid electricity generation in India using intermediate pyrolysis

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ABSTRACT

The environmental impact assessment of a process over its entire operational lifespan is an important issue. Estimation of life cycle emission helps in predicting the contribution of a given process to abate (or to pollute) the environmental emission scenario. Considering diminishing and time-dependent effect of emission, assessment of the overall effect of emissions is very complex. The paper presents a generalized methodology for arriving at a single emission discounting number for a process option, using the concept of time value of carbon emission flow. This number incorporates the effect of the emission resulting from the process over the entire operational lifespan. The advantage of this method is its quantitative aspect as well as its flexible nature. It can be applied to any process. The method is demonstrated with the help of an Intermediate Pyrolysis process when used to generate off-grid electricity and opting biochar route for disposing straw residue. The scenarios of very high net emission to very high net carbon sequestration is generated using process by careful selection of process parameters for different scenarios. For these different scenarios, the process discounting rate was determined and its outcome is discussed. The paper also proposes a process specific eco-label that mentions the discounting rates.

Symbols

d	damage or and unit emission [kg of CO_2]
D	effective damage [kg of CO_2]
i	damage profile rate [kg/year]
j	discounting rate [%]
L	life of equipment [years]
N	abatement target [years]

Subscripts & superscripts

A, B, C	type of activities that release emissions (classified as ‘negative’)
D, E	type of activities that absorb emissions (classified as ‘positive’)
i, j, k	$= 1, 2, 3$ ... (loop counters)
n	$= 1, 2, 3$ ... (loop counters)

Abbreviations

Al	aluminum
C	carbon
CdTe	cadmium telluride
CH_4	methane
CI	cast iron
CN	carbon neutrality
CO_2	carbon dioxide
CSR	corporate social responsibility
Cu	copper
Disp	disposal phase of LCA
EU	European Union
FCCE	full cycle carbon emission
GHG	greenhouse gases
GWP	Global Warming Potential
h	hour
IIT	Indian Institute of Technology
ILCD	International Reference Life Cycle Data
IP	intermediate pyrolysis
IPCC	Intergovernmental Panel On Climate Change
kWh	kilo-watt-hour
LCA	Life Cycle Assessment
Manu	manufacturing phase of LCA
Mat	material phase of LCA
MATLAB	Matrix Laboratory
MJ	megajoule ($= 10^6$ J)
Mn	manganese
MS	mild steel
N_2O	nitrous oxide
pH	potential of hydrogen
PV	photovoltaic
RoHS	restriction of hazardous substances directive
SS	stainless steel

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t	tonne (= 1000 kg)
Trans	transportation phase of LCA
TVCF	time value of carbon flows
Wt.	weight

1. Introduction

New processes are constantly being developed, tested, introduced and practiced, driving progress and change. It is essential to know how sustainable a new process is before it is introduced. This would help understand new inventions in terms of the net benefit they bring to the society (An Impact Assessment Method for Technology | PRé Sustainability [WWW Document], 2014). It is rightly pointed out that in implementing the Kyoto Protocol, the decisions required to take over many borderline or "gray" areas (Maclaren and Ford-Robertson, 2013). Precise determination of the effect of emission on the environment of a process option is certainly a gray area till date.

Life Cycle Assessment (*LCA*) is widely used method to determine the environmental emission for a product or process option (Pant et al., 2011). It is a systematic, analytical and comprehensive method to identify, evaluate, and minimize the environmental impact of a process (Morrison and Sinclair, 1998). It considers all the stages of a product's life cycle, such as, raw material, processing, manufacturing, use, and end-of-life (Williams, 2009). *LCA* accounts the emission occurred in the different phases of its life cycle of any process. The emission released during material, manufacturing, transportation and disposal phase can be grouped under embedded emission, while an aggregate effect of emission during the operation of the process can be called as process emission (Fritsche and Rausch, 2009). These emission numbers are then arithmetically accounted to obtain the net emission during the life cycle of a process. The net emission (difference between emission reduction and emission generation during different phases of *LCA*) is considered as an environmental burden (for brevity herein referred as simply burden), also referred as carbon (*C*) footprint in the literature (Wiedmann and Minx, 2008), from a process option. The flowchart for such methodology is as shown in the Fig. 1.

It is essential to summarize emission released from different processes and comment the way its components are estimated. Table 1 gives the emission numbers for certain of the energy generation process options. It is important to note that renewable energy compared to conventional energy has low emission numbers per unit of electricity generated. Wind energy has the lowest emission number per unit of electricity. The combustion of biomass is emitting less emission (being carbon neutral) compared to coal and should be preferred, provided the biomass have obtained from a sustainable source, i.e. biomass obtained from the land not reserved for the forest.

While comparing different processes, specifically the energy generation processes, the component of emission incurred in preparing the facility and plant (including machinery) is very important in accounting the life cycle emission. For most of the renewable energy processes such emission is either not correctly determined or not accounted at all and therefore it do not adequately reflect the life cycle emission numbers. For example, while considering emission from solar photovoltaic (*PV*), its embedded emission i.e. emission generated to prepare cells is not considered to its fullest extent. Emission from lead oxide that is used in solar cells as a catalyst for contact formation (Pecht, 2014; Ellison and Szabo, 2006) and emission embedded towards battery containing lead is not considered ("www.gov.uk/bis," 2014). The corresponding emission is at present exempted under the Restriction of Hazardous Substances Directive (*RoHS*) guidelines (RoHS Regulations 2012, 2014). Cadmium telluride (*CdTe*) thin-film *PV* modules in solar *PV* panels are explicitly allowed by the *RoHS* to contain cadmium, even though cadmium is restricted in all other electronics items (*RoHS* regulation as extended on May 27th, 2011). In real terms, if such exempted emission is considered solar energy will become exorbitantly high in terms of environmental burden (Voorspools et al., 2000). The forest area submerged while constructing a hydro power plant reduces the capacity of the earth to absorb large carbon dioxide (CO_2) through photosynthesis. This is an example of un-accounted embedded emission in case of hydro power plant. Similarly, change of land use (land reserved for forest when used for agricultural purpose) is also an example of writing off embedded emission for agricultural products. Large inconsistency in accounting embedded emission is also observed, due to the selection of inconsistent methods for the study, especially in case of nuclear power plants. Subjectivity in the embedded analysis is such that the total emission from nuclear power plant determined by different authors varies from as low as 3–11.5 kg of CO_2/kWh to as high as 112–166 kg of CO_2/kWh (Sovacool, 2008).

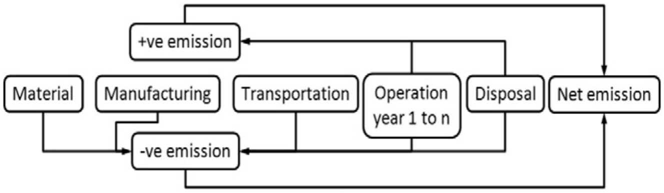

Fig. 1. Present method of accounting the effect of emission under *LCA* approach.

Table 1
Emission estimates from various power generation process options (gCO_2/kWh) (Sovacool, 2008).

Process	Specifications	Emission gCO_2/kWh
Wind	2.5 MW, offshore	9
Hydroelectric	3.1 MW, reservoir	10
Biogas	Anaerobic digestion	11
Solar thermal	80 MW, parabolic trough	13
Biomass	Co-combustion (wood + coal)	14
Solar PV	Polycrystalline silicon	32
Geothermal	80 MW, hot dry rock	38
Natural gas	Gas turbine (combined cycle)	443
Fuel cell	Hydrogen from gas reforming	664
Diesel	Various generator & turbine types	778
Coal	Various types + scrubbing	960

It its worth to review the way emission is estimated from the *LCA* analysis, its components and its limitations. The emission information obtained from *LCA* during the use phase is presented by linking it with objective function (kg of CO_2/kWh for energy generation processes). On the other hand the emission values obtained during material, manufacturing, transportation and disposal phases are constant in nature and is not linked with any operational variable. There is ambiguity in adding these two different forms of emission numbers. For instance, it is argued that emission burden for semiconductor manufacturing, should be normalized per area of wafer instead of per kg of chip (Duque Ciceri et al., 2010). It is also observed that there is variability in the distribution of burdens among different components of the life cycle of different processes. One process may use less resources during the use phase (e.g. renewable energy products), this may be at the cost of more resources warranted at the time of manufacturing (Finnveden, 2000). Further the ratio of energy used and emission generated in material stage compared to manufacturing stage is also not constant throughout the products (starting from a simple hair dryer to a digital copier) (Duque Ciceri et al., 2010) and therefore it is not advisable to treat these emissions "*at par*" (by simple addition). Studies that obtained lifetime CO_2 generation per unit of electricity reported that estimating life of the plant and assuming other operational parameters is not a straightforward task, for instance load factor of the plant, in case of wind turbine sites varies from, 30% to 20% within the regions of