Analysis of Uncertainty in Resource Intensity of Solid Freeform Fabrication

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- Capture the variance of resource intensity estimates for solid freeform fabrication processes based on inherent parameter, model selection, and data source effects
- Conduct a case study to verify results for the Fused Deposition Modeling (FDM) process using a Life Cycle Assessment approach (LCA)
- Develop a set of recommendations for further research & development

Sources: Designforum.net, University of Iowa

- Error and uncertainty in resource intensity estimates are poorly recorded in the literature, particularly for rapid prototyping, rapid manufacturing, aka solid freeform fabrication processes

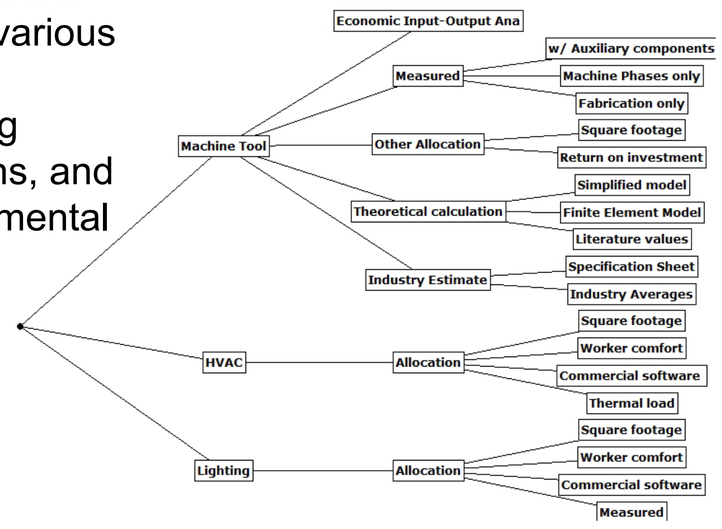
LCA Uncertainty			
Data Quality	Wiedema & Wesnaes (1996)*	Vigon & Jensen (1995)^	
Parameter	Sonnemann, et al. (2003)*	Lo, et al. (2005)*	Yuan, et al (2006)*
	Heijungs & Frischknecht (2005)^	Cellura, et al. (2011)*	Venkatesh (2011)*
Scenario	Williams, et al. (2009)[1]	Peças, et al. (2009)*	Huijbregts (1998)
Model	McKone & Bogen (1992)*	Benetto, et al. (2008)[1]	Hertwich, et al. (2000)*
	Nicholson, et al. (2009)	Bahr & Steen (2004)[1]	
Surveys	Heijungs & Huijbreg (2004)	Reap, et al. (2007)	
	Ross, et al. (2002)	Lloyd & Ries (2011)	
Holistic	Plevin (2010)*		

- Increasing concern about product effects on the environment and society require a more holistic accounting of the impacts of manufacturing operations. LCA is a common tool for estimating the resource consumption and impacts of processes and process chains, but wrought with uncertainty in current literature. The intersection of these areas is first addressed here with a novel methodology in a case study on FDM

Summary of Life Cycle Assessments of Solid Freeform Fabrication processes

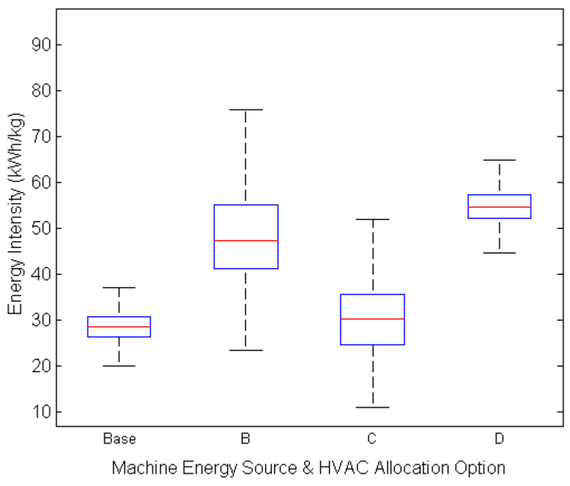
Life Cycle Assessments	Bottom Line(s)	Inclusion of FDM	Uncertainty
Aubin (1994)	Cost	Yes	No
McMains (1995)	Cost/ Qualitative	Yes	No
Luo, et al. (1999/2000)	Environment	No (SLA)	No
Hopkinson, et al. (2006)	Cost/ Environment	No (SLS)	No
Telenko, et al. (2011)	Cost/ Environment/ Qualitative	No (SLS, IM)	No

- Measured energy consumption during printing for various random parts on 3 machines with HVAC and lighting
- Conducted a Monte Carlo simulation including various energy consumption assumptions, differing geographical locations, and data sets for environmental impacts
- Recorded 2304 sets of conditions



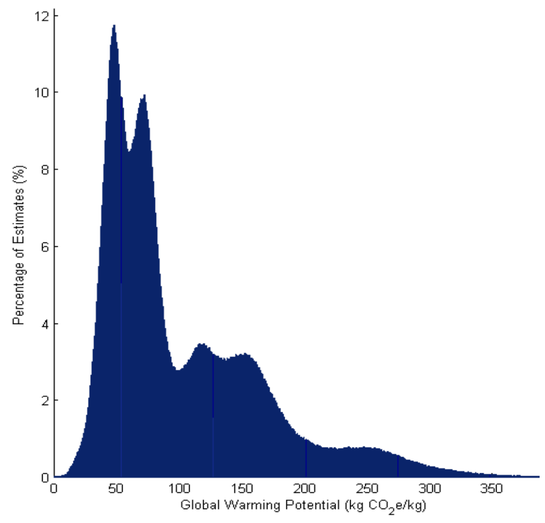
Simple Effects

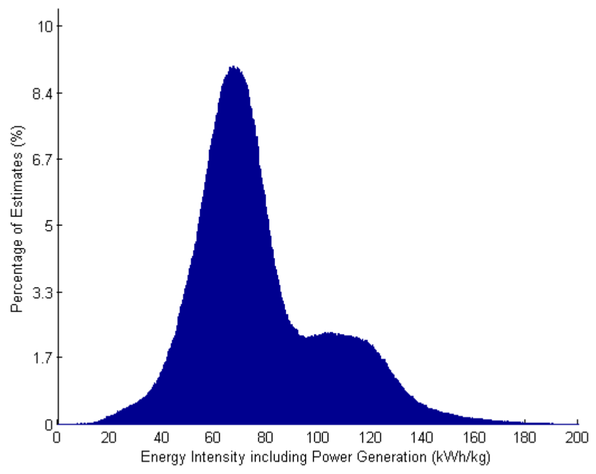
- Combined effects of model (researcher choices of how parameters combine and interact) and scenario (geographic, temporal, or technological) effects contribute largely to uncertainty
- Figure description
  - B: target machine, area HVAC allocation, uniform treatment
  - C: proxy machine, target area HVAC allocation, uniform treatment
  - D: proxy machine and HVAC area allocation, lognormal treatment



Aggregate Results

- Global warming potential (left) and energy consumption (right) estimates for all sets of conditions by frequency of value estimate





Conclusions

- Point estimates are poor references for decision makers
- Process LCAs lend themselves to iterative assessment allowing arbitrarily detailed process chain estimates
- Studies should report basic statistics on their results for improved interpretation and comparison
- Proxy estimates, even with the same technology reduce the accuracy significantly
- Model choices should be strongly scrutinized

- Include other flows: mass, information, human capital, etc.
- Sub-meter components of the machine for improved granularity
- Repeat analysis with additional lifecycle stages
- Extend to additional production technologies
- Combination with process physics simulations for improved predictions from both techniques