

Energy and CO₂ Implications of Music Delivery Options

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Outline

- ▶ Previous work of environmental effects of ICT
- ▶ Modeled Scenarios
- ▶ Data and Assumptions
- ▶ Results
- ▶ Sensitivity and Uncertainty Analysis
- ▶ Summary



Environmental Implications of ICT

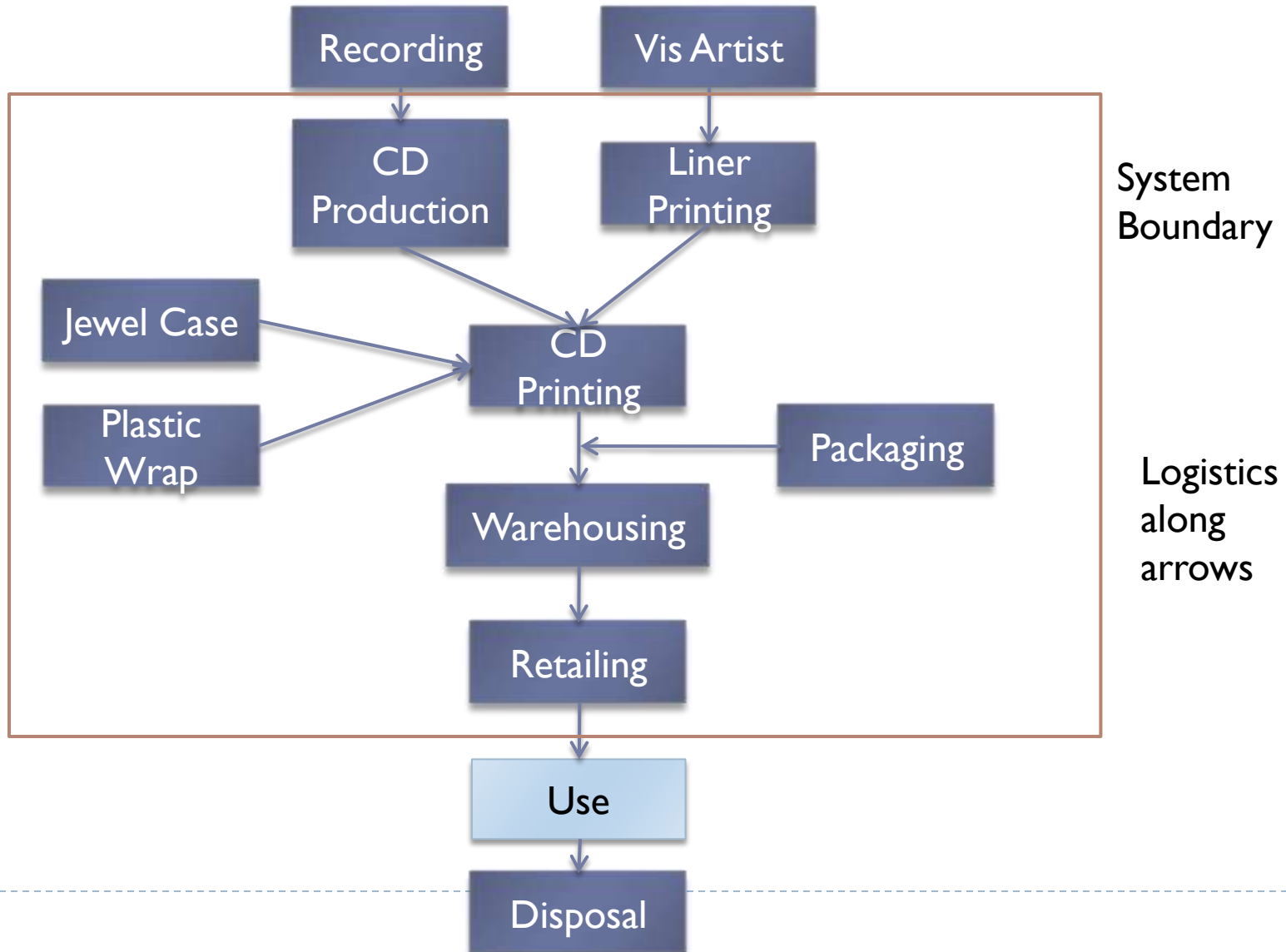
- ▶ Increasing interest of how informational and communication technology (ICT) effects the environment
- ▶ Previous studies have assessed:
 - ▶ Telecommuting vs. commuting (Atkyns 2002)
 - ▶ Online vs. traditional retail (Matthews 2001, Abukhader 2004)
 - ▶ Electronic delivery of news (Toffel 2004)
 - ▶ Online vs traditional DVD rental (Sivaraman 2007)
 - ▶ Material intensity of online music (Turk 2003)
- ▶ Generally ICT has won by:
 - ▶ Dematerialization
 - ▶ Reduced Logistics
- ▶ However, continuing energy use rise of internet data centers and personal ICT products -> renewed interest in issue

Goal and Scope of this study

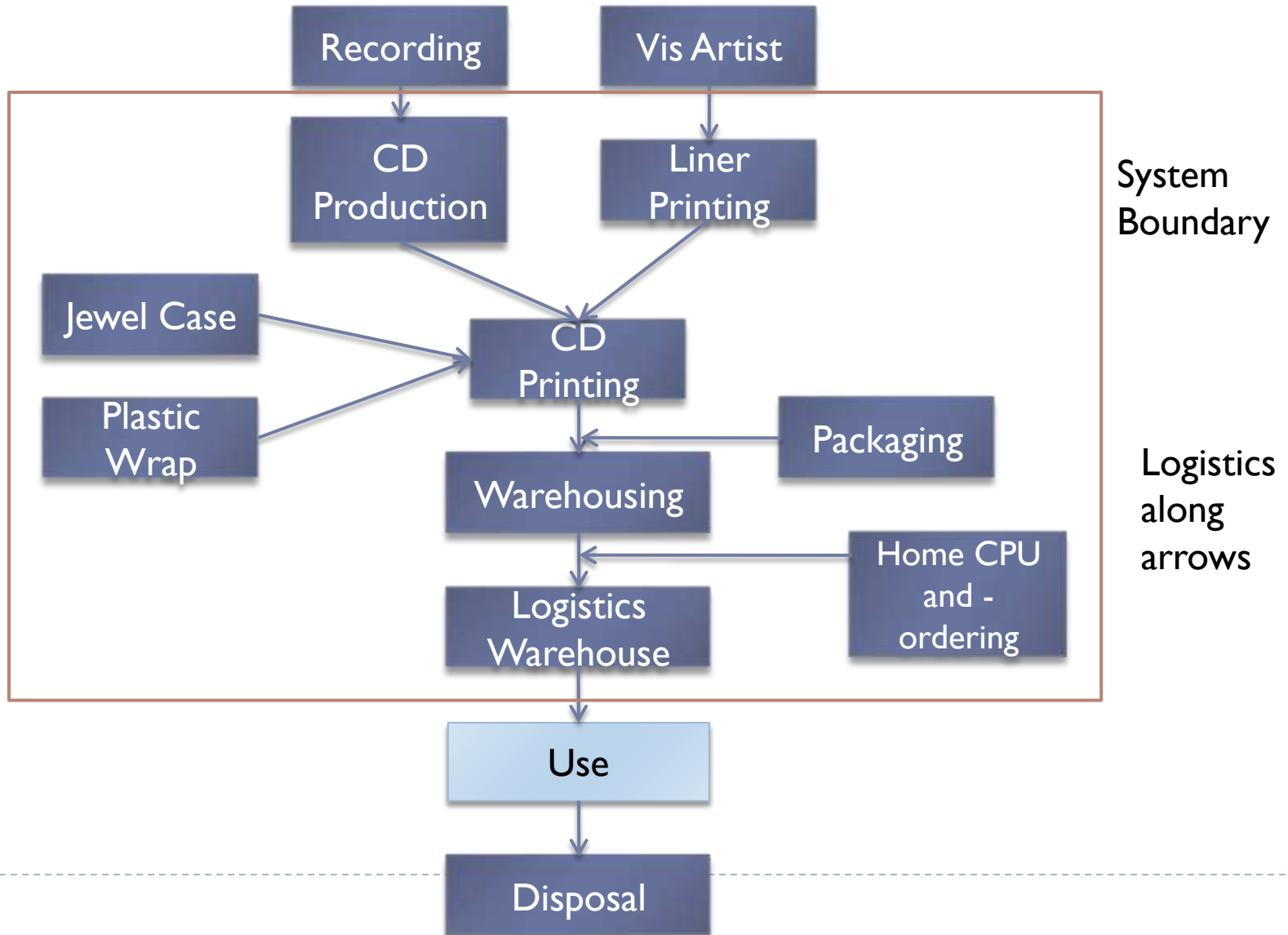
- ▶ Examine as realistically as possible cumulative energy and CO₂ emissions for delivery of 1 album of music via 6 alternative scenarios:
 - ▶ 1) Album packaged on CD and delivered via traditional retail methods
 - ▶ 2) Album published on CD and delivered by light-duty truck through an online e-tail provider
 - ▶ 3) Album published on CD and delivered by express air through an online e-tail provider
 - ▶ 4) Album downloaded as mp3/mp4 files from an online music service and used digitally
 - ▶ 5) Album downloaded as mp3/mp4 files from an online music service and burned to CD-R for digital and CD use (no CD packaging)
 - ▶ 6) Album downloaded as mp3/mp4 files from an online music service and burned to CD-R for digital and CD use, stored in individual CD packaging, i.e., slimline jewel cases
 - ▶ System Diagrams shown below
-



Traditional Retail Model

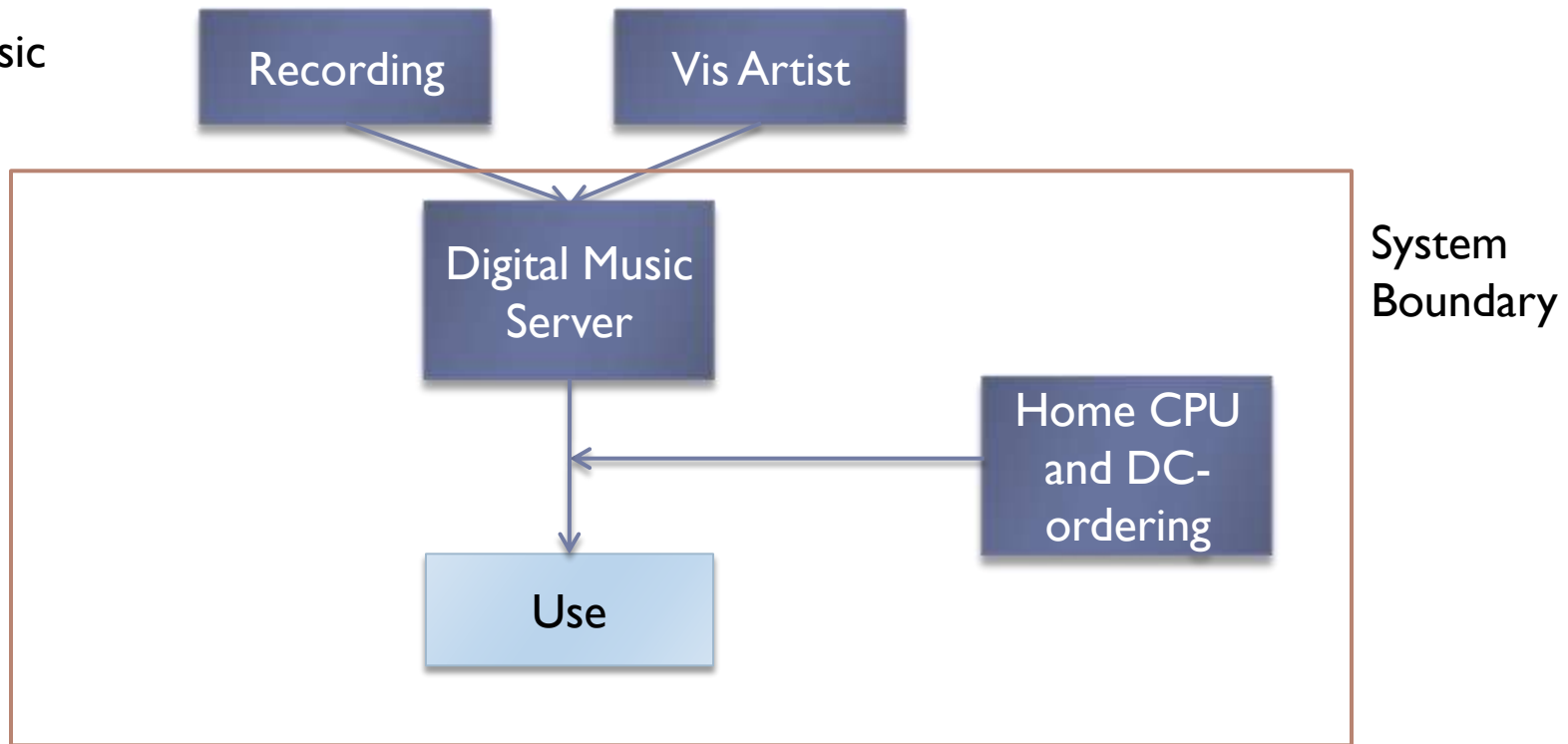


E-commerce Delivery Model



Online Music Model

Online Music



Functional Unit Question

- ▶ **Assumption: After burning digital album on CD, functionally equivalent**
 - ▶ Can use in either digital or CD format
 - ▶ Because of this, can ignore production of laptop, CD player, iPod, etc.
 - ▶ Sound quality not similar but do consumers care?
- ▶ **In practice, probably used differently**
 - ▶ Digital downloads used more in computers and digital music players
 - ▶ CDs used more in cars, CD decks, etc



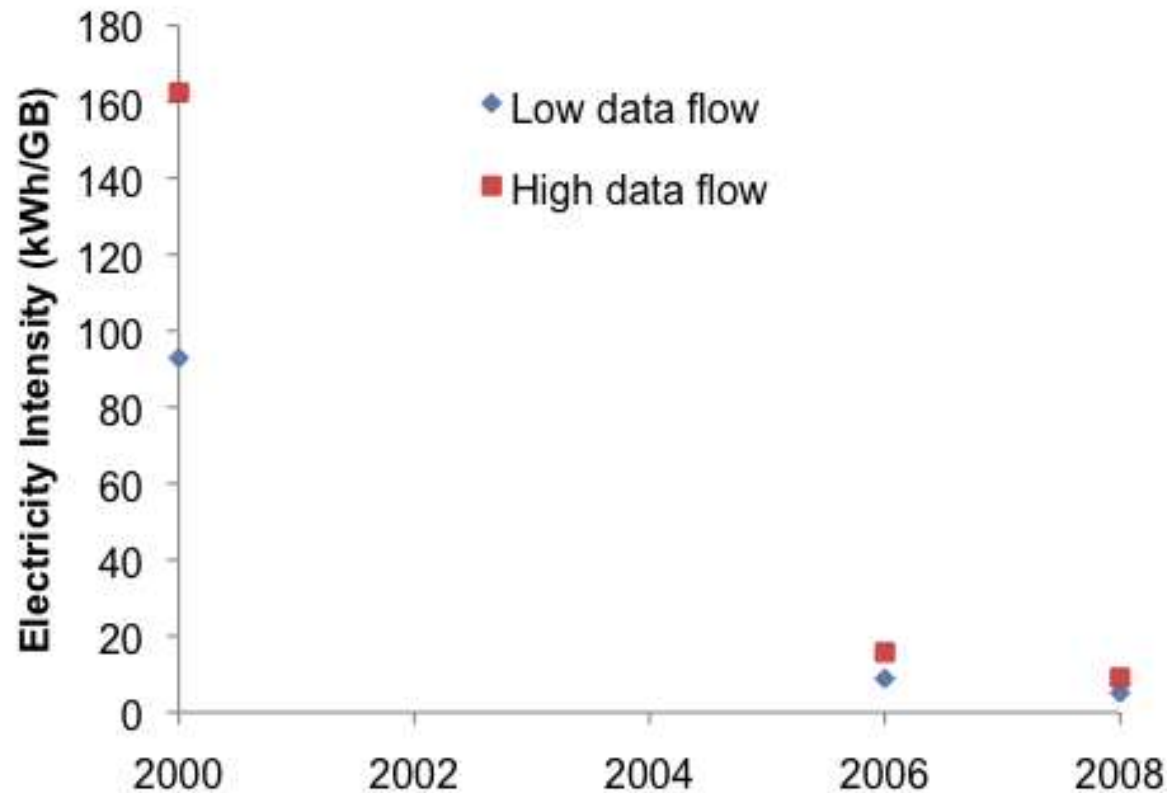
Assumptions and Data

- ▶ Gather >3 primary data points and assume triangular distribution Monte Carlo simulation
- ▶ Production location varied through assumed grid mix uncertainty (300-900 g CO₂e/kWh)
- ▶ Data gathered for
 - ▶ CD and packaging production (reports, Ecoinvent, IO-LCA)
 - ▶ Cardboard packaging for retail/etail (EPA WARM, EDF Paper Calculator)
 - ▶ Distances and delivery energy (Logistics companies, GREET, previous work), large range
 - ▶ Warehouse and Retail store energy use (gov't sources, previous work)
 - ▶ Home CPU use for ordering (assumption range, Energy Star data)



Internet Backbone Energy Use

- ▶ Taylor and Koomey (2008)
- ▶ Assume 60-100 MB album size (iTunes, Amazon averages)



Customer Transport

- ▶ Shown in previous work to be significant in logistics
- ▶ Difficult to model given large variation in fuel economy, distance, etc

$$E/item = \frac{(mi)(E/gal)}{(mi/gal)(p/veh)(items/p)}$$

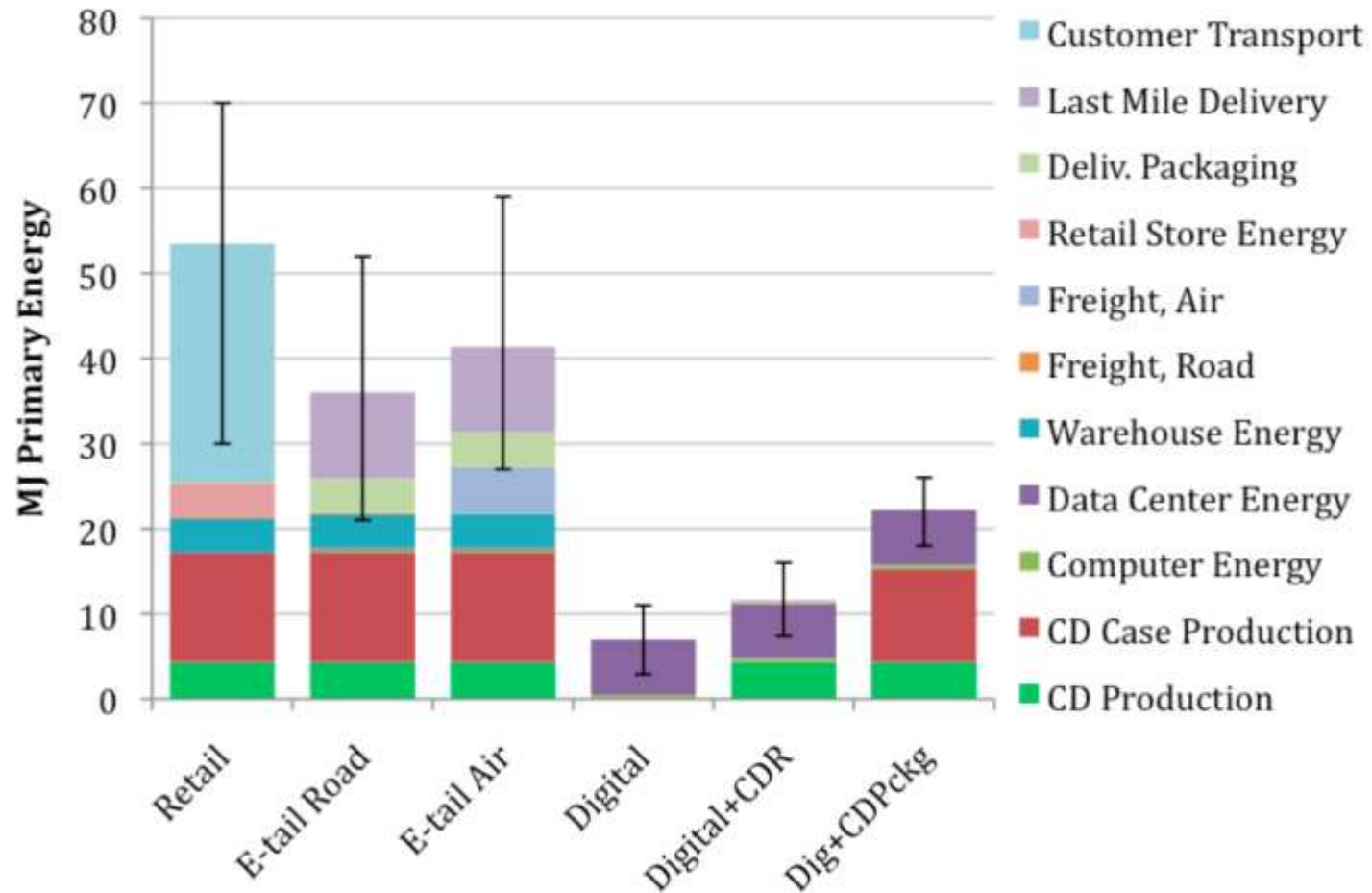
- ▶ Assumed model simulates distance, fuel economy, passengers per vehicle, and purchased items per person using realistic ranges
- ▶ Assumed correlation in distance and items/person-trip and distance to retail/distance for etail delivery



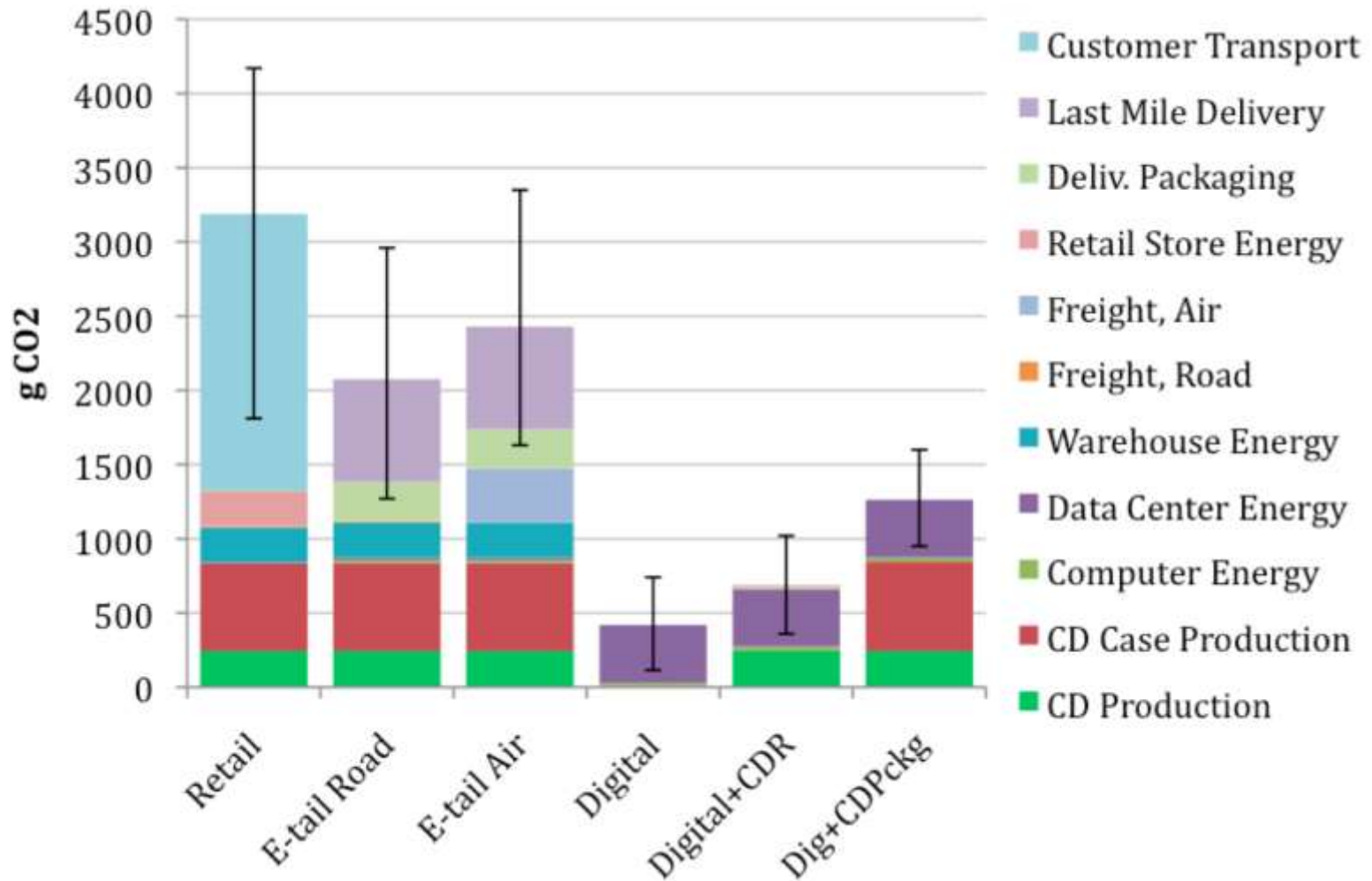


Results

Cumulative Energy Demand/album



Similar for CO2 emissions



Summary Statistics

- ▶ CD/packaging production: 32-69% of total
- ▶ Customer Transport and Last Mile: 52% of retail, 24-28% etail
- ▶ Other significant contributors (Retail/Etail)
 - ▶ Warehousing
 - ▶ Retail Store
 - ▶ Individual cardboard packaging (Etail)
- ▶ Upstream internet usage:
 - ▶ As important as CD/CD-R production



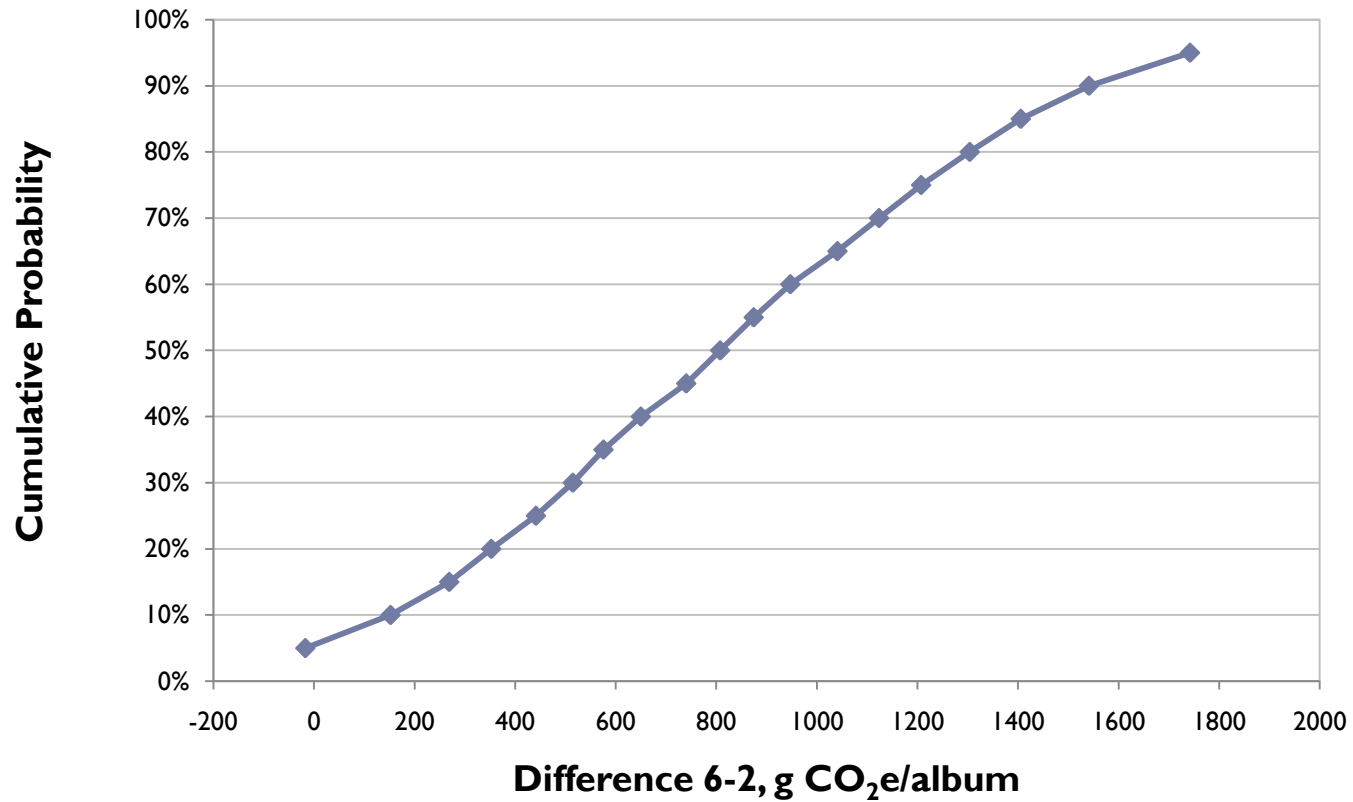
Uncertainty and Variability

- Rank correlation importance shows variable's contribution to uncertainty/variability

	Retail	E-commerce Road	E-commerce Air	Dig	Dig+CDF	Dig+CD +Pckg
Driving Distance	0.71					
Fuel Economy	-0.33					
Warehouse: electricity	0.1	0.11	0.11			
Retail: Gas	0.04					
Jewel Case Production	0.59	0.85	0.81			0.06
CD Production	0.07	0.07	0.07		0.23	0.23
Last Mile Energy		0.49	0.47			
Data Centers		0.07	0.06	0.99	0.96	0.95
Computer Energy		0.07		0.05	0.06	0.06
E-tail packaging		0.13	0.12			
E-tail Road Freight		0.05				
E-tail Air Freight			0.29			



Effect of Correlated Errors



Discussion

- ▶ Dematerialization increases environmental performance but partially offset by internet energy use
- ▶ Sensitivity—what parameters could flip result
 - ▶ Retail with zero customer transport emissions (bicycle/walk)
 - ▶ 5 hours of web browsing for online shopping
 - ▶ 260 MB data transfer (lossless files)
- ▶ Suggested Future Work:
 - ▶ Customer usage patterns: are they different?
 - ▶ Other types of online music: single song vs album, subscription, etc
 - ▶ Energy use of streaming audio/video—large upstream data transfer



Questions

- ▶ Contact: clweber@cmu.edu

