GreenFPGA: Evaluating FPGAs as Environmentally Sustainable Computing Solutions

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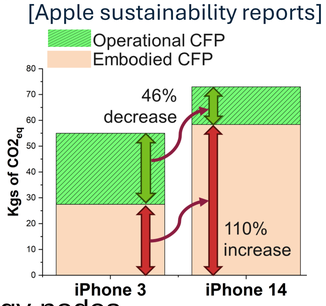
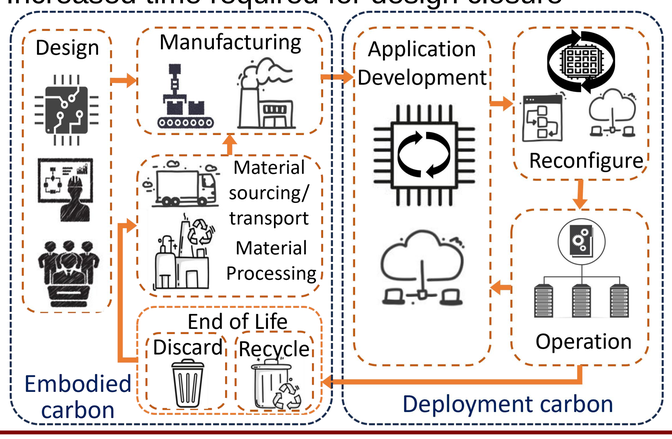
Introduction & Background

- The information and computing technology (ICT) industry contributes to 3-5% of the world's total carbon footprint (CFP)
- **Embodied CFP:**
  - Manufacturing, design, recycle
- **Deployment CFP:**
  - End-user operation, programming hardware
- Embodied CFP has increased over time due to :
  - Lower yields in newer technology nodes
  - Increased time required for design closure

[Apple sustainability reports]

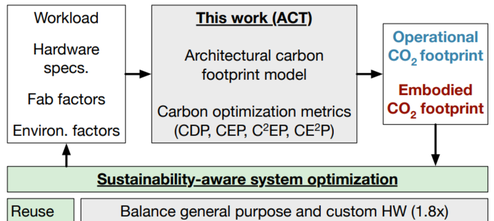


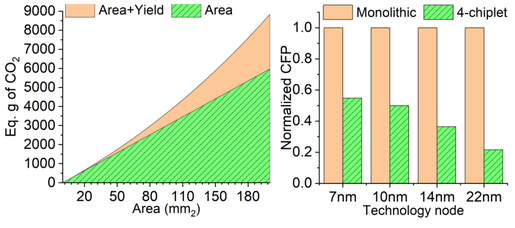


Prior Work

ACT [*ISCA 2022*]
- Architectural model for embodied CFP
- Based on industry reports

ECO-CHIP [*HPCA 2024*]
- Heterogeneous integration (HI) for sustainability
- Estimates design and advanced packaging CFP
- Evaluates operational CFP





FPGAs for Sustainability

Reconfigure for multiple applications

Long lifetime

GreenFPGA Framework

Input params

- Area of chip
- Tech node
- Volume of chips
- Recyclable fraction
- Defect densities (yield)
- Energy used by design
- #Employees in design house
- #Logic gates

- Number of apps
- Peak power
- Average power
- App lifetime
- App development time

GreenFPGA

Embodied carbon
- **Design carbon:** Design house sustainability reports
- **Manufacturing and packaging carbon:** Prior art and industry sustainability reports
- **EOL carbon:** Government recycling reports

Deployment carbon
- **App development carbon:** Based on development time
- **Operational carbon:** Based on peak power and duration of use

Outputs

Embodied and operational carbon

CFP in equivalent grams of CO_2

Comparison between ASICs and FPGAs

$$C_{ASIC} = \sum_{i=1}^{i=N_{app}} (C_{emb,i} + T_i \times C_{deploy,i})$$

$$C_{FPGA} = C_{emb,i} + \sum_{i=1}^{i=N_{app}} T_i \times C_{deploy,i}$$

Embodied CFP of FPGAs is amortized across multiple applications

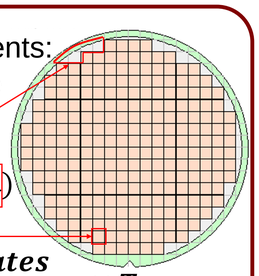
C_{FPGA} - Total FPGA CFP
C_{emb} - Embodied carbon
C_{deploy} - Deployment carbon
N_{app} - Number of applications
T_i - Application lifetime

GreenFPGA Models

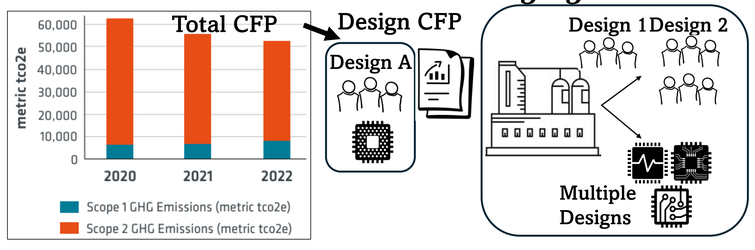
Embodied CFP: Comprises of four components: Manufacturing, design, packaging, end of life

$$C_{emb} = C_{des} + C_{mfg} + C_{pkg} + C_{EOL}$$

$$C_{mfg} = CFPA \times (Die\ area + Wasted\ area)$$



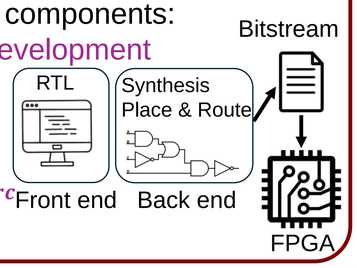
$$C_{des} = C_{emp} \times total\ emp\ per\ chip \times \frac{\#gates}{avg\ \#gates} \times T_{proj}$$



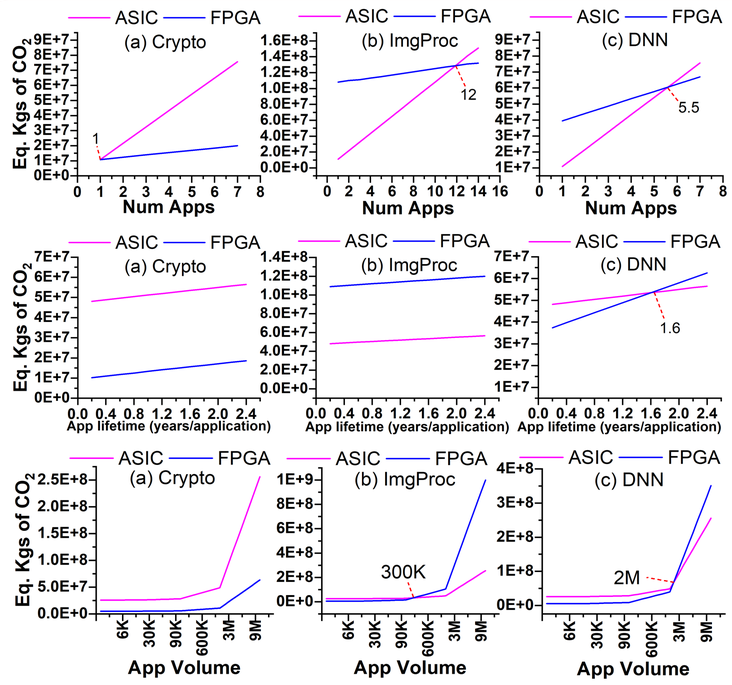
Deployment CFP: Comprises of two components: Operational carbon and application development

$$T_{app-dev} = T_{frontend} + T_{backend} + T_{app,config}$$

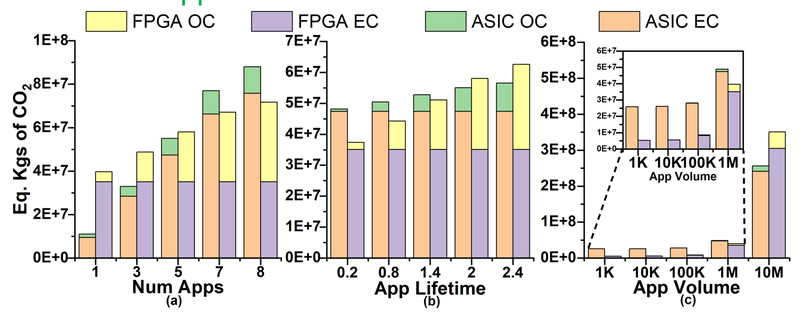
$$C_{app-dev} = P_{app-dev} \times T_{app-dev} \times C_{src}$$



Results and Key Takeaways



- GreenFPGA helps identify scenarios where FPGAs serve as sustainable alternatives to ASICs
- Example, for a DNN application FPGAs are best for application lifetime <1.6 yr/app, 2M app volume, and > 5.5 number of applications



- Embodied CFP of FPGA stays the same, while that of ASIC increases as the number of applications increase
- Increase in operational CFP of ASIC is lesser compared to FPGA as application lifetime increases

Conclusion

- Embodied CFP of the FPGA is amortized across multiple applications unlike ASICs
- FPGAs are a good solution for sustainably for large number of application, low application volume, and short application lifespans

https://github.com/ASU-VDA-Lab/GreenFPGA