

# Adaptive Hardware for Energy-Efficient FPGA-based Data Centers



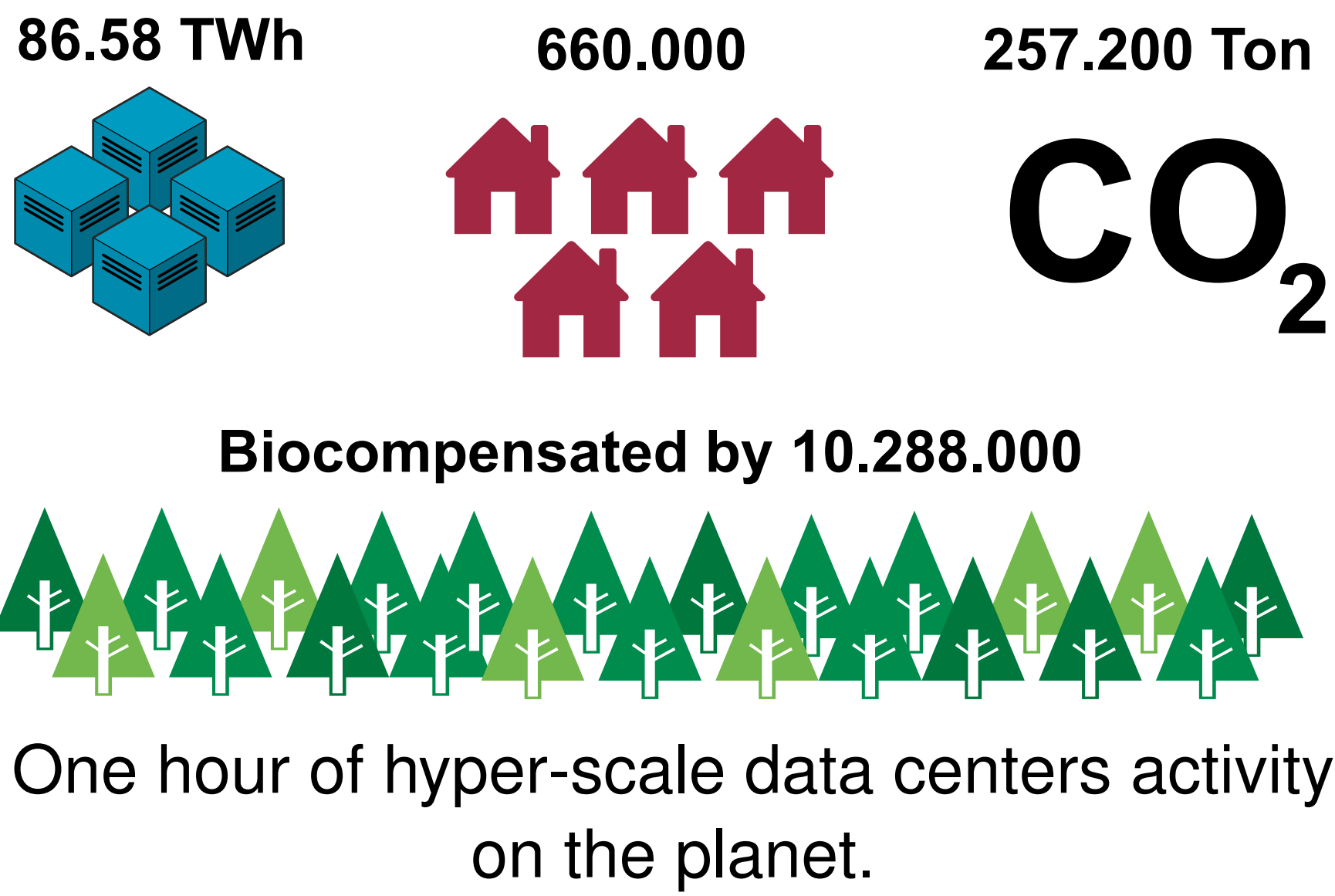
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## Problem Definition



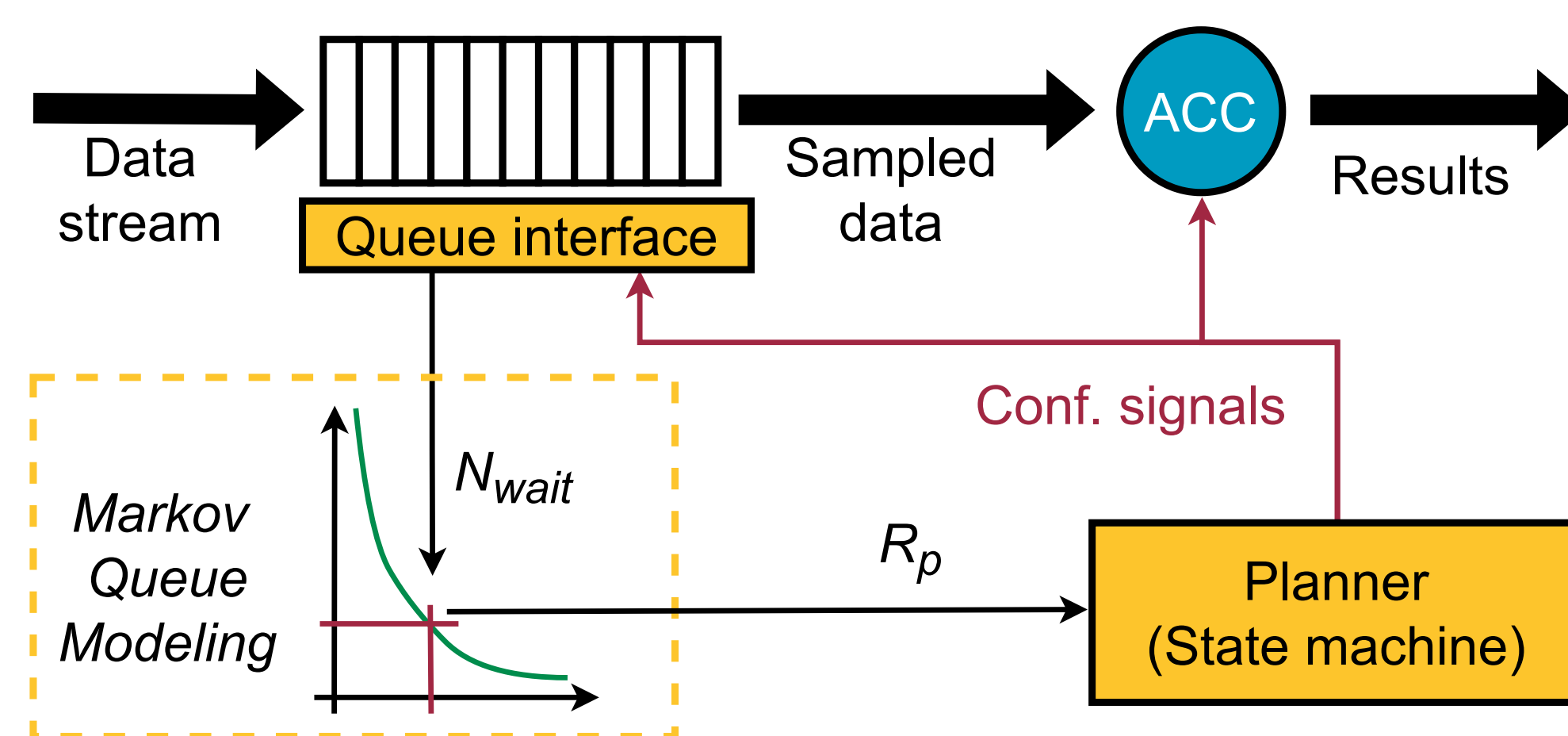
Thinking sustainably has become fundamental in modern society. The *2030 Agenda for Sustainable Development* [1] highlights the importance of considering the IT sector. FPGA has excellent sustainability characteristics [2], but its utilization to make data centers green is challenging [4]:

1. **FPGA proliferation** ● ●: we need new optimizations to make FPGA attractive for data centers
2. **Adaptive systems** ● ●: we need to adapt the FPGA-based data center to future workloads
3. **Green data distribution** ● ●: we need to move the workload to areas with less ecological impact
4. **Management tools** ● ●: we need tools that help the development and adoption of FPGAs
5. **Power models** ●: we need to differentiate the consumption between green and fossil energy

## Accelerator Level - Hardware optimizations

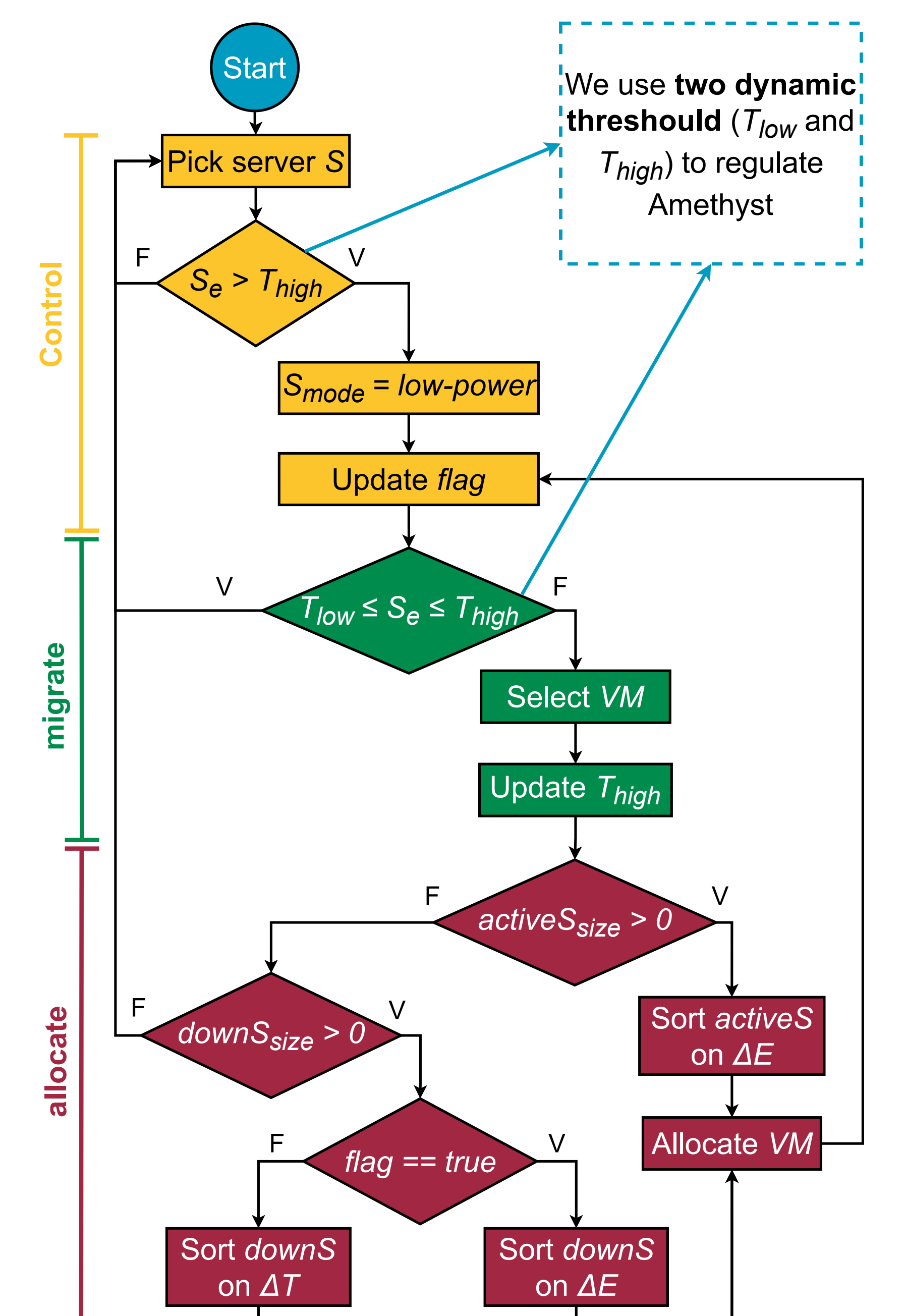
Considering Vitis HLS and HBM platforms, we identified **applicable hardware optimizations** [3] by restructuring and enriching the basic functionality in C++:

- Host-HBM double-buffering
- HBM-Kernel bandwidth exploitation
- Dataflow restructuring
- Resource sharing



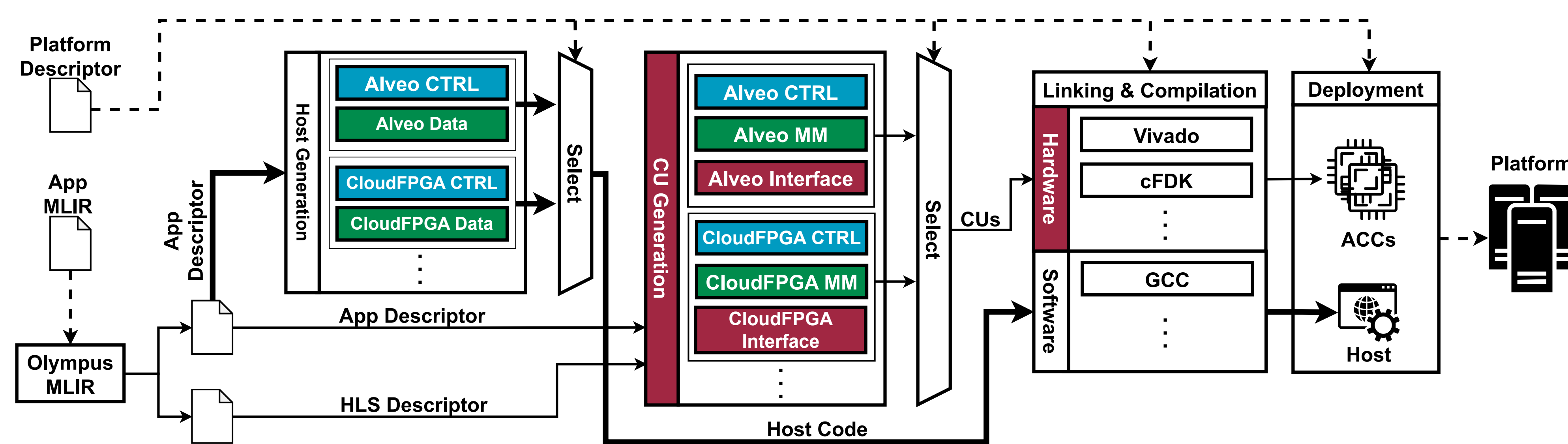
We proposed a **framework for developing adaptive accelerators** [5] based on approximate techniques and response time prediction.

## Data Center Level - Amethyst



**Amethyst** algorithm to support adaptive FPGA. It controls the computation to favor green energy consumption and limits the fossil one.

## System Level - Proteo

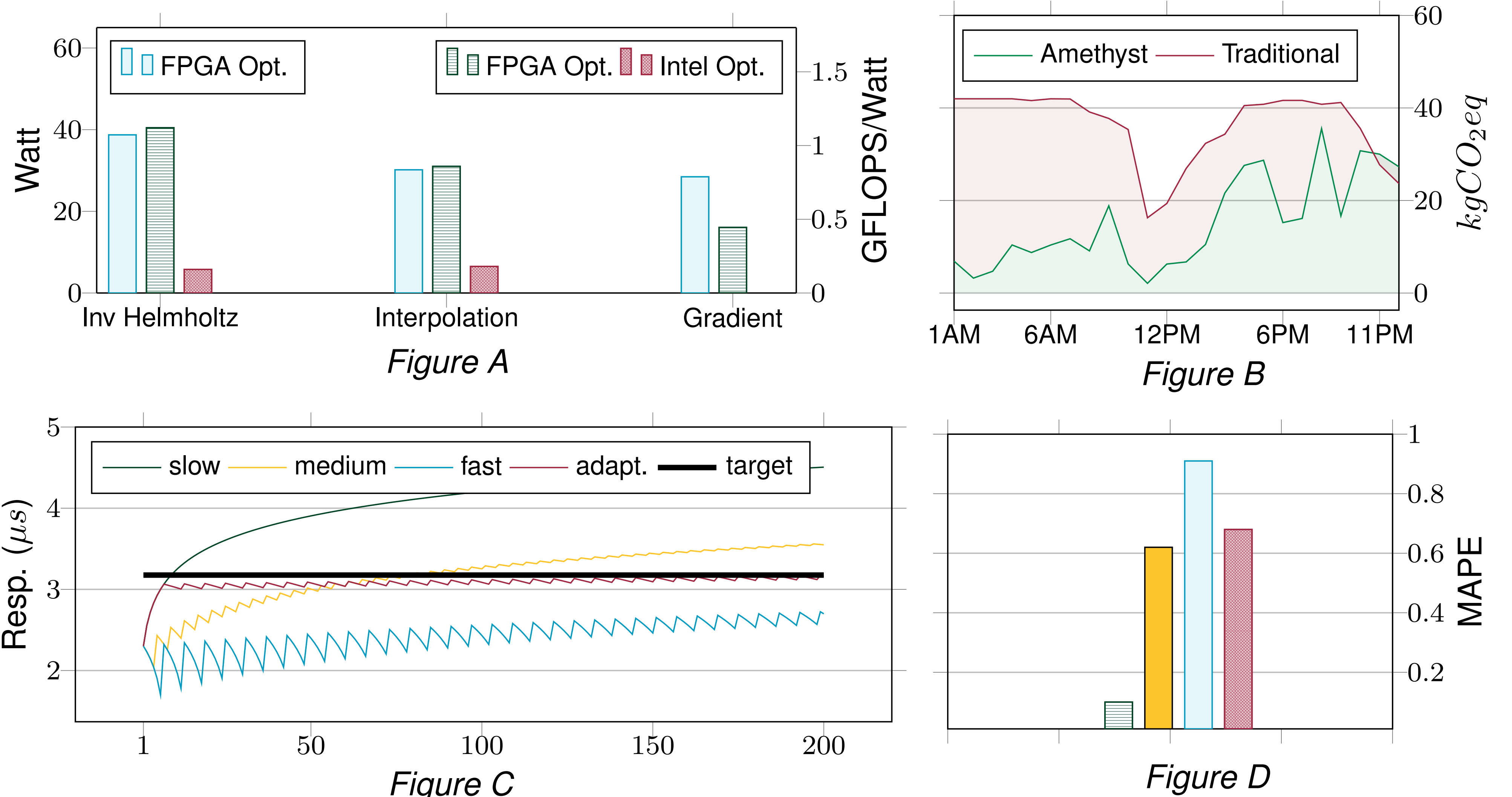


**Proteo** generates optimized memory and intra-kernel connections (*stream-oriented* and *memory-oriented*), and integrates different open-source HLS compilers to provide quick FPGA development.

## References

- [1] D. of Economic and S. Affairs. *2030 Agenda for Sustainable Development*. 2015. URL: <https://sdgs.un.org/2030agenda>.
- [2] C. Pilato et al. "A System Development Kit for Big Data Applications on FPGA-based Clusters: The EVEREST Approach". In: *2024 Design, Automation & Test in Europe Conference & Exhibition (DATE)*. 2024, pp. 1–6.
- [3] S. Soldavini et al. "Automatic Creation of High-Bandwidth Memory Architectures from Domain-Specific Languages: The Case of Computational Fluid Dynamics". In: *ACM Transactions on Reconfigurable Technology and Systems (TRETS)* (2022).
- [4] M. Tibaldi and C. Pilato. "A Survey of FPGA Optimization Methods for Data Center Energy Efficiency". In: *IEEE Transactions on Sustainable Computing* 8.3 (2023), pp. 343–362.
- [5] M. Tibaldi et al. "Dynamically-Tunable Dataflow Architectures Based on Markov Queuing Models". In: *Electronics* 11.4 (2022).

## Evaluation



(A) Power and performance result comparisons for different operators when we apply our hardware optimizations ( $24.5\times$  improve) [3]. (B) Amethyst **Global Warming Potential** compared to traditional data center computed on Alibaba workload (40% reduction). (C) System response time trend when we apply our adaptive controller [5]. (D) MAPE error when we apply our adaptive controller (Legend on Fig. C) [5].

## Acknowledgments

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