FPGA Innovation Research in the Netherlands: Present Landscape and Future Outlook

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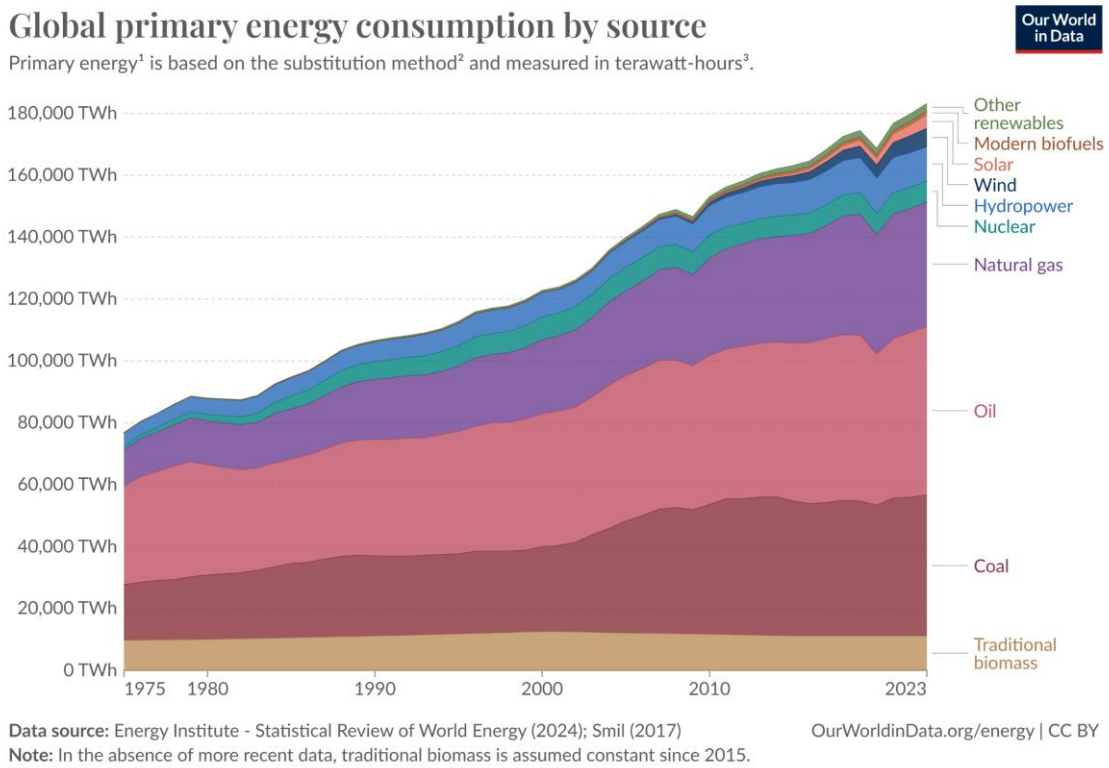
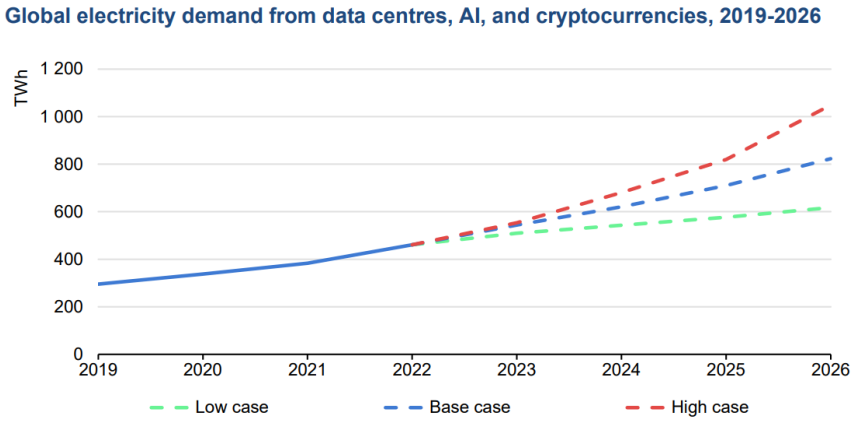
Motivation

Global challenges

- Global energy consumption increases
- Significant amounts of energy to data centers
- The need for data-driven applications increases
- (Part of the) solution: decrease energy consumption for data intensive applications
- FPGAs balance performance and efficiency



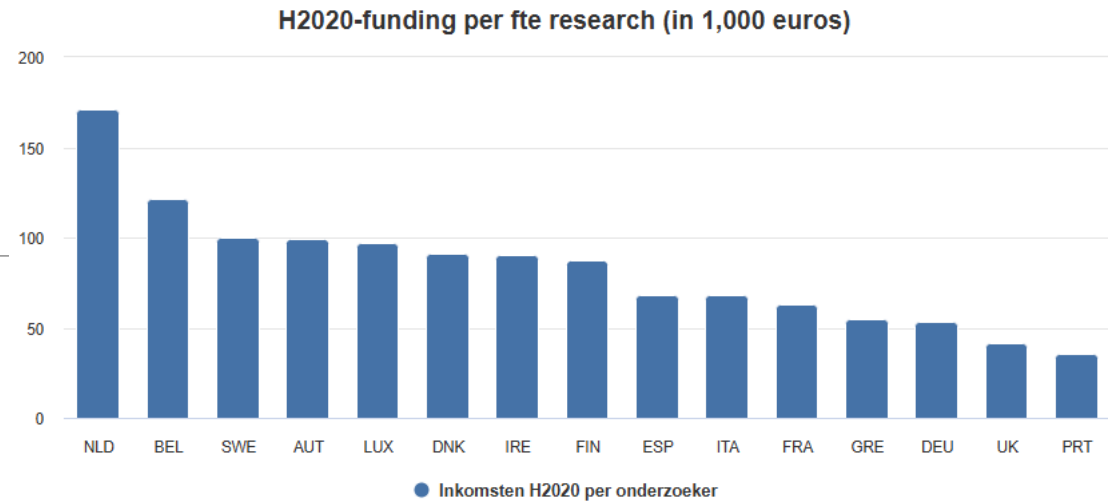


Electricity 2024 Analysis and forecast to 2026 – International Energy Agency

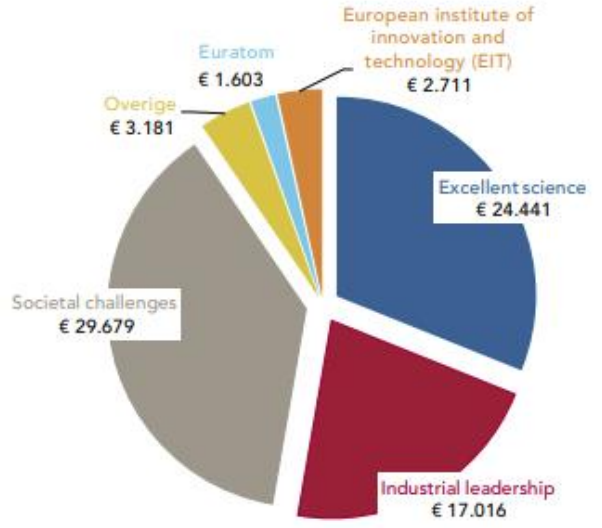
Motivation

Role of the Netherlands

- The Netherlands has significant participation in EU projects
- The Netherlands makes a comparatively high contribution to “Excellent Science”
- Includes strategic goals such as
  - Autonomous technologies (AI)
  - Technologies to combat climate change
- FPGA technology can be pivotal to those challenges



The Netherlands in the EU Framework Programmes – Rathenau Instituut



De Nederlandse wetenschap in de European Research Area – Rathenau Instituut

Motivation

- Netherlands makes major global contributions in **engineering** and **technology** related fields
- Netherlands is home to major research institutes that innovate FPGA technology:
  - European Space Research and Technology Center (ESTEC)
  - National institute for Nuclear and High energy physics (Nikhef)
  - The Netherlands Institute for Radio Astronomy (ASTRON)
- Need for in-depth understanding on how FPGAs can tackle global challenges
- Requires more than simply knowing the capabilities and limitations of FPGA technology
- How do contributions in the FPGA innovation field align with current computational needs and challenges

Our survey

As part of the FIRE project, we wrote a **survey paper on FPGA related research in the Netherlands**

This survey provides insight into

- Which organizations contribute to the field of FPGA research in the Netherlands
- Into which major themes can FPGA research in the Netherlands be categorized
- Active areas of FPGA research and applications in the Netherlands
- A future perspective on FPGA research in the Netherlands

Method

Survey

3-step approach to gathering relevant literature:

1. **Scopus-wide** search for literature in the past 5 years
2. In-depth search through **relevant publishers** (ACM and IEEE)
3. In-depth search through **select conferences and journals of high relevance**:
   - International Symposium on Field-Programmable Gate Arrays (FPGA)
   - International Symposium on Field-Programmable Custom Computing Machines (FCCM)
   - International Conference on Field Programmable Logic and Applications (FPL)
   - International Conference on Field-Programmable Technology (FPT)
   - ACM Transactions on Reconfigurable Technology and Systems (TRETS)

Literature selection based on relevance to FPGA innovation and significance of application

Output: 212 relevant publications

Themes

Categorizing the resulting literature

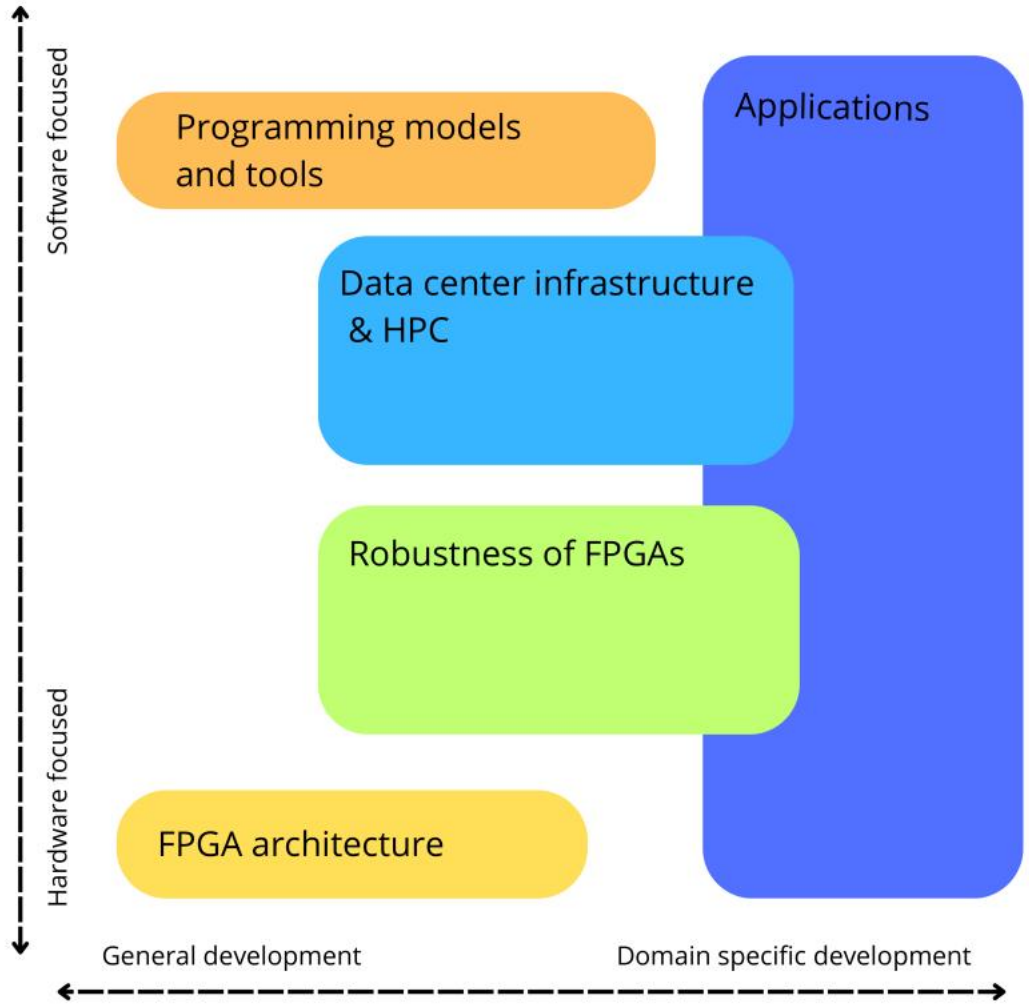
- 5 resulting themes

Type of technology

- Software focused research
- Hardware focused research

Domain specificity

- Application specific
- Generally applicable



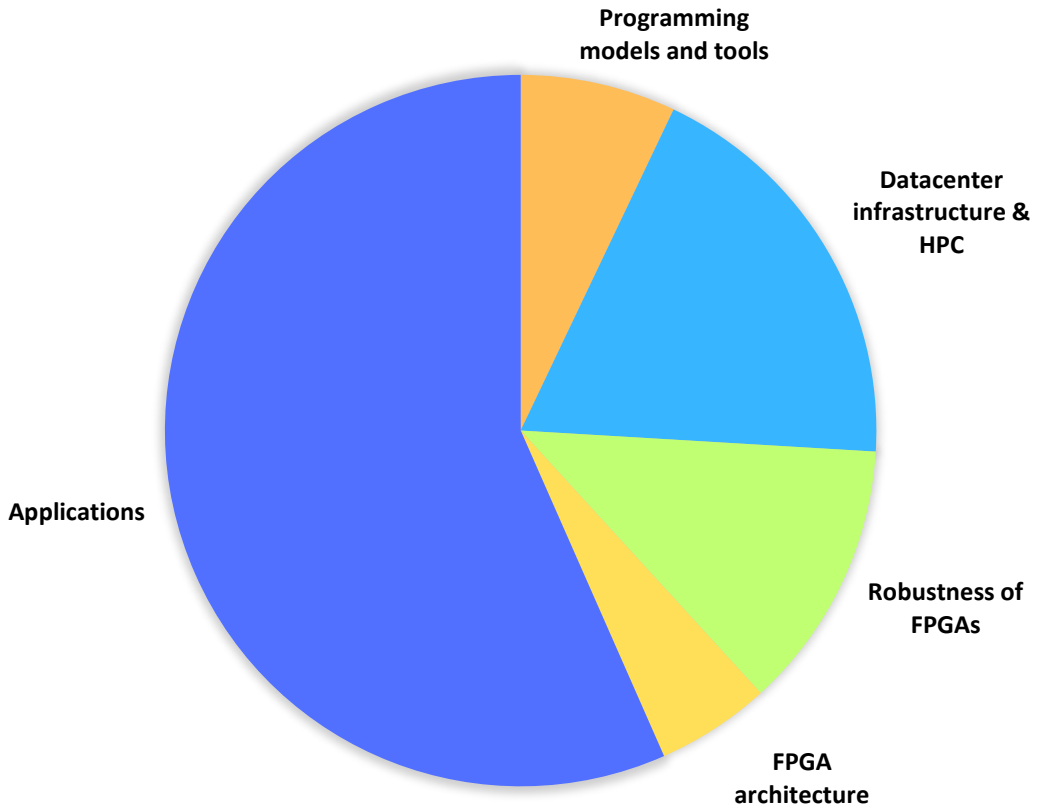
Research output per theme

Most research output is application-focused

- 120 research papers
- 6 largest applications selected for in-depth review

Most significant other themes

- Datacenter infrastructure & HPC (40 papers)
- Robustness of FPGAs (26 papers)



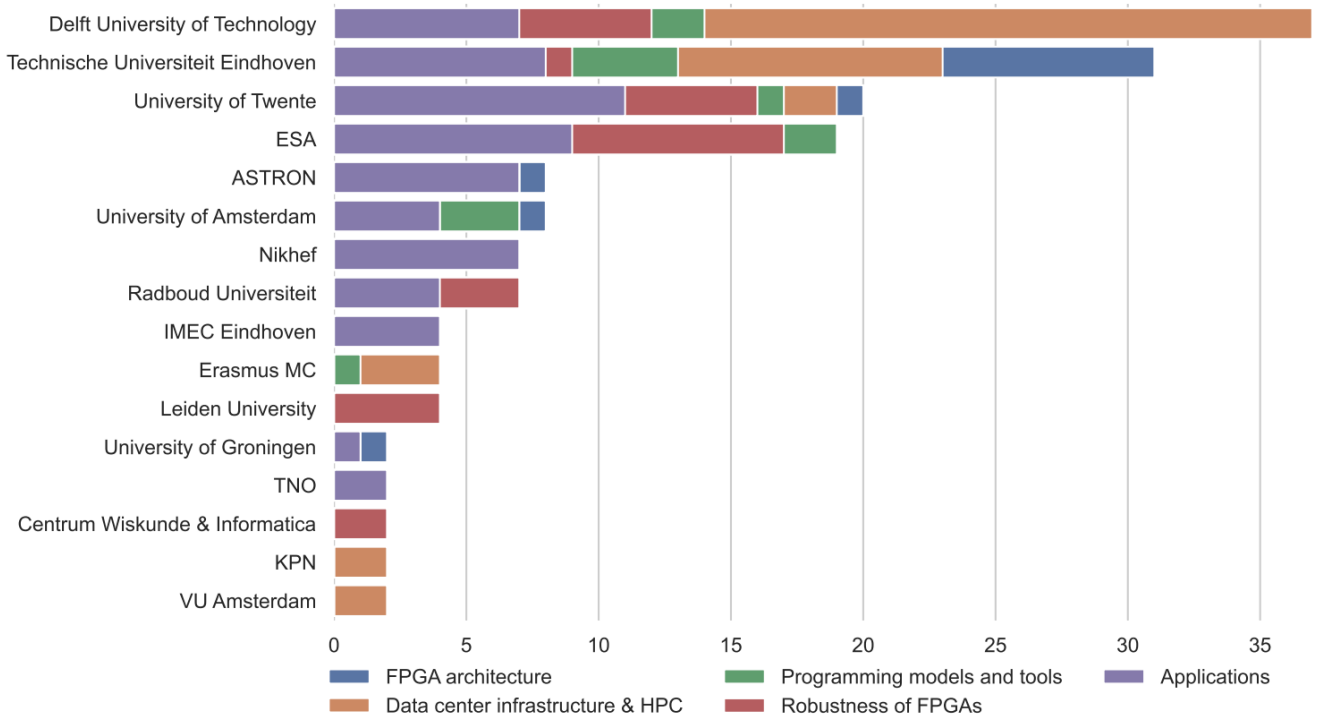
Research output per organization

Most research output from 3 TU's

- Major focus Delft:
  Data center infrastructure & HPC
- Major focus Eindhoven:
  FPGA architecture
- Major focus Twente:
  FPGA Robustness

High research output from research organisations:

- ESA (ESTEC), ASTRON and Nikhef



Research highlights

FPGA architecture

Explore advanced computer architecture concepts

- Eliminating bottlenecks in existing computer architectures

Main architecture topics

- Near-memory computing
  - Implemented in various applications (e.g. Bioinformatics and simulation)
- Coarse-Grained Reconfigurable Architecture (CGRA)
  - Coarse-grained application-mapping templates
  - Evaluation of coarse-grained ASIC designs
- Network-on-chip
  - NoC designs focussed on FPGA hardware constraints
  - Reliable NoCs with predictable latency

Data center infrastructure & HPC

FPGAs contribute in multiped domains in data centers

- Logic between hardware layers
- Dedicated accelerators / co-processors

Main datacenter infrastructure & HPC topics

- Big data processing & analytics
  - Development of high-level workflows for FPGAs, increasing applicability to general infrastructures
- Distributed computing
  - Used in large-scale graph processing and neural networks
- Optical hardware communication
  - FPGA as a communication system for improved bandwidth
- High performance computing
  - Involvement in several European projects implemented FPGAs in HPC

Programming models and tools

Models and software tools

- Enabling efficient and effective FPGA design workflows
- Focusing on heterogenous computing

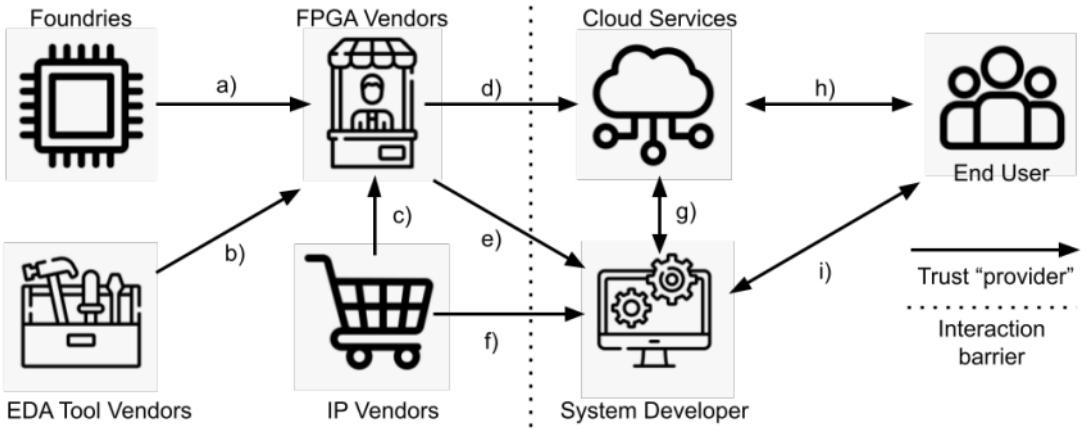
Main programming models and tools topics

- Models and frameworks
  - Hardware description tools with increased abstraction (HLS)
  - Models for distributing workload in heterogenous systems
- Prediction performance of synthesized designs
  - Various methods employing machine learning
  - For large-scale and heterogenous computing system

Robustness of FPGAs

Robust FPGA design is a multi-dimensional challenge

- It involves several stages of the FPGA system's production chain
  - Platform design, FPGA design, application
  - Dutch research mainly on user/application side



FPGA robustness is divided into

- Reliability / Security

Reliability of FPGA hardware design

- Adapting existing IP for high-reliability applications (e.g. space)

- **Security** of FPGA designs and algorithms
  - Integrating device capabilities with secure design requirements

Applications

FPGAs are versatile and can be applied in a wide variety of domains

Six most featured applications are covered

- Machine learning
  - Acceleration, SNNs, co-design
- Astronomy
  - For interfacing and signal processing
- Particle physics experiments
  - FPGAs in several components of particle accelerators
- Quantum computing
  - Control and readout of quantum computers
- Space applications
  - Hardware resilient to space environment
- Bioinformatics
  - Processing large datasets, DNA, proteins etc.

Input from industry

Complementing the academic perspective

- Input from nine companies through a questionnaire

Questions on several topics

- To gain insights into which applications FPGAs are used
- To understand the motivations and bottlenecks of using FPGAs in industry

Key findings

- FPGAs are widely used for highly parallel, high bandwidth and throughput
- Flexibility of development and production compared to ASIC
- Applications: control systems, near-memory processing, resilient designs

Conclusion and discussion

A comprehensive survey of Dutch research output

- Analyzing over 200 FPGA related papers
- Revealing major research directions
- Highlighting the importance of FPGA research in the NL
- Involving the perspective of industry

Future work

- Research included by affiliation
- The extent of involvement is not documented
- Further insight into specific research groups within the NL