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Operational characterization of stellarator and tokamak type fusion power plants from an energy system perspective

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Background

- Fusion power plants are still not considered in European long-term energy system studies [1,2]. Yet, they could represent an abundant and reliable local energy resource.
- The operating performance of power plants significantly affects the unit commitment and dispatch. Since fusion reactor design is under ongoing development, the parametrization of fusion power plants is an active area of research.

Study Objective

- The goal of the present work is to specify and energetically represent the operation and dynamics of fusion power plants from an energy system perspective.
- Special focus is given on time and operation mode dependent self-consumption of the plant. The basis of the parametrization is a 1GW net electrical power output plant.

Fusion Reactor Operational Characterization

Modelling System

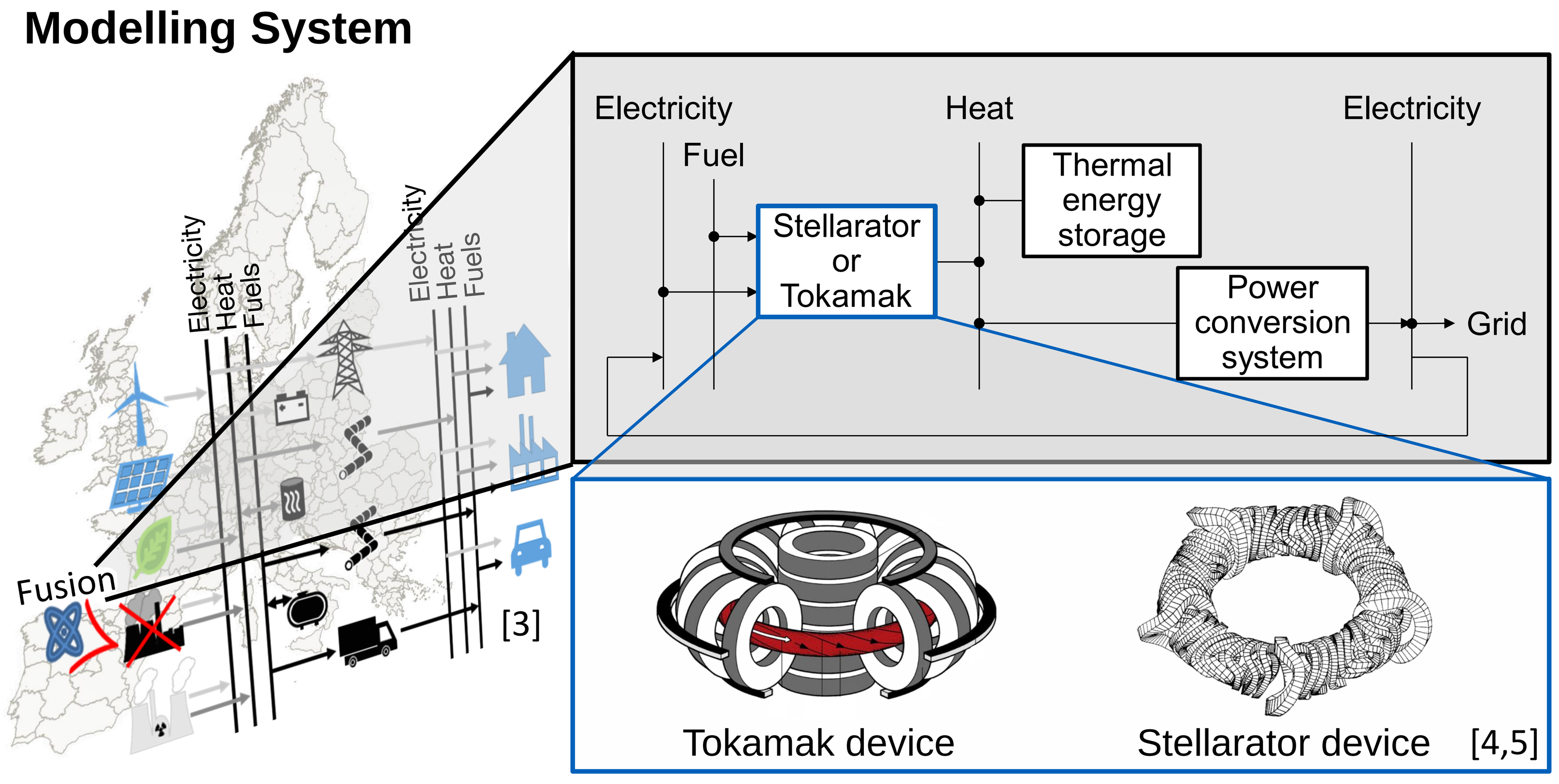
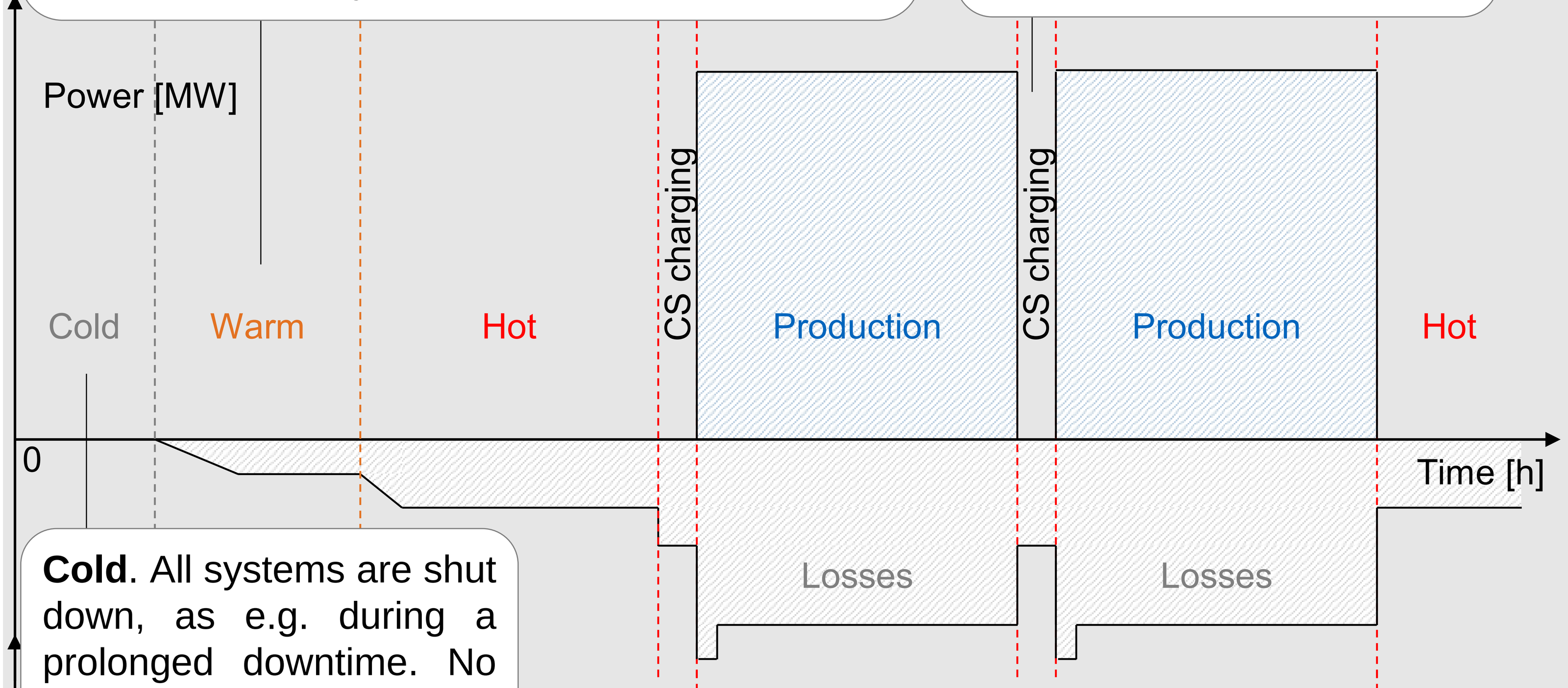


Figure 1: Main fusion power plant components from an energy system perspective

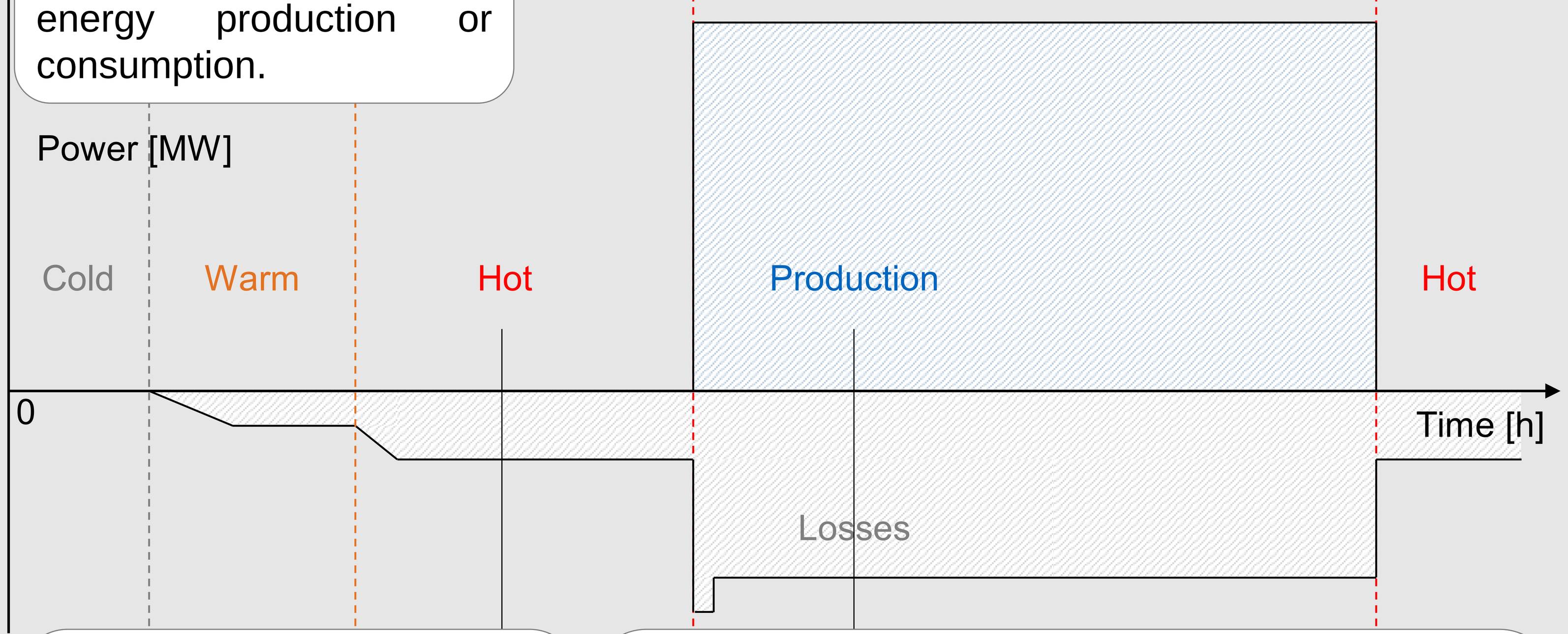
Identified Operating States

Warm. Magnetic fields are generated by superconducting coils which require the operation of a cryogenic plant for their cooling. In the plasma chamber high vacuum conditions are created and maintained. Facilities for maintenance and monitoring of the plant are assumed to actively consume electricity.

CS charging. In case of the tokamak, magnets for the generation of the central solenoid (CS) field are being charged. All subsystems from the hot state are energized.



Cold. All systems are shut down, as e.g. during a prolonged downtime. No energy production or consumption.



Hot. All subsystems from the warm state are energized. Additionally, the tritium plant is activated as well as the heat transfer system (HTS) in part load with a reduced power consumption.

Production. All subsystems from the hot state are energized. Plasma and burn control are active. The heating and current drive systems (HCD) are working with nominal load. The reactor generates thermal energy from the burning plasma.
At the beginning of this state HCD systems are operating with increased power demand for a few minutes during the plasma start-up.

Figure 2: Tokamak (above) and stellarator (below) operation states and their transitions

Power Requirements

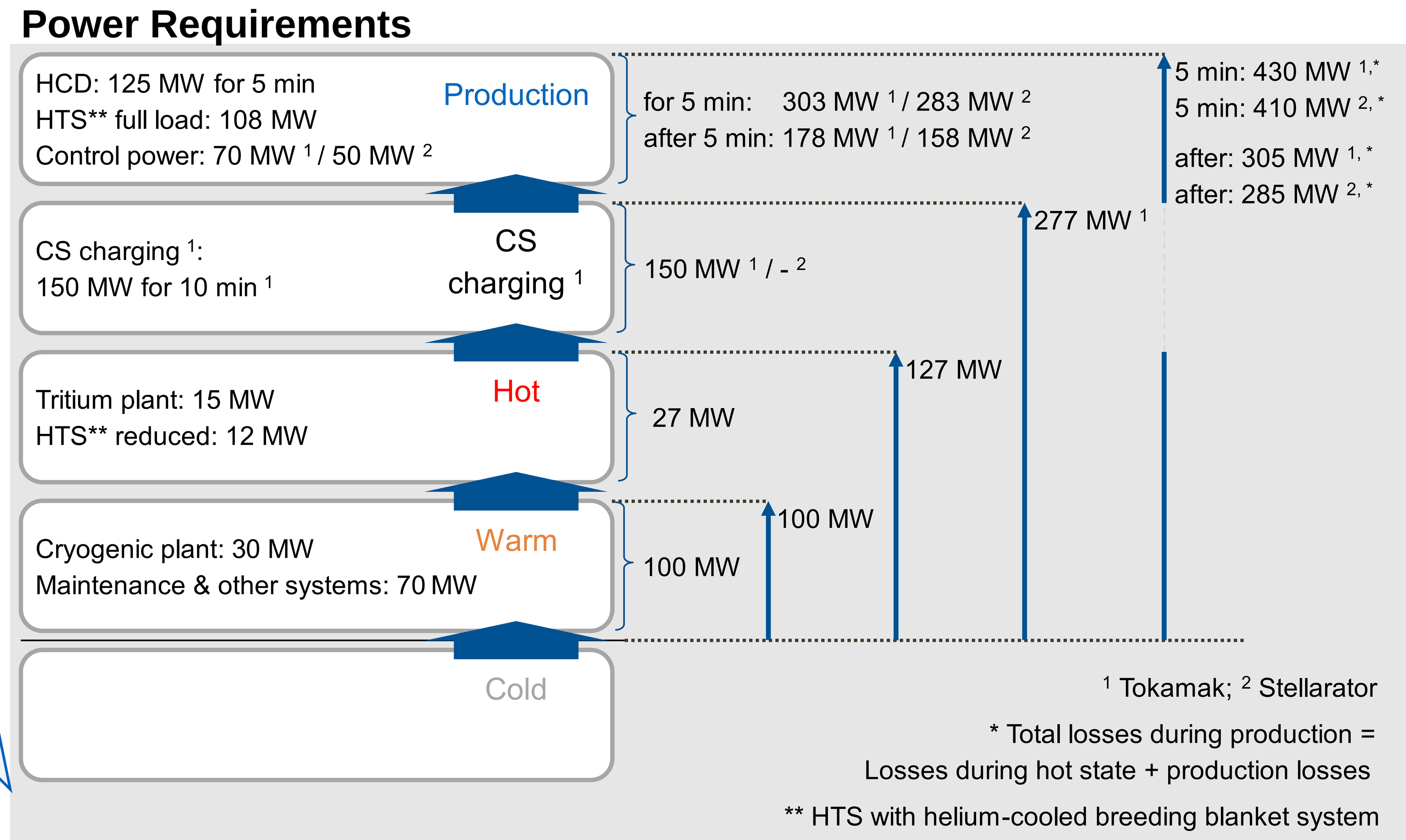


Figure 3: Power requirements of operating states

Resulting Power Balance

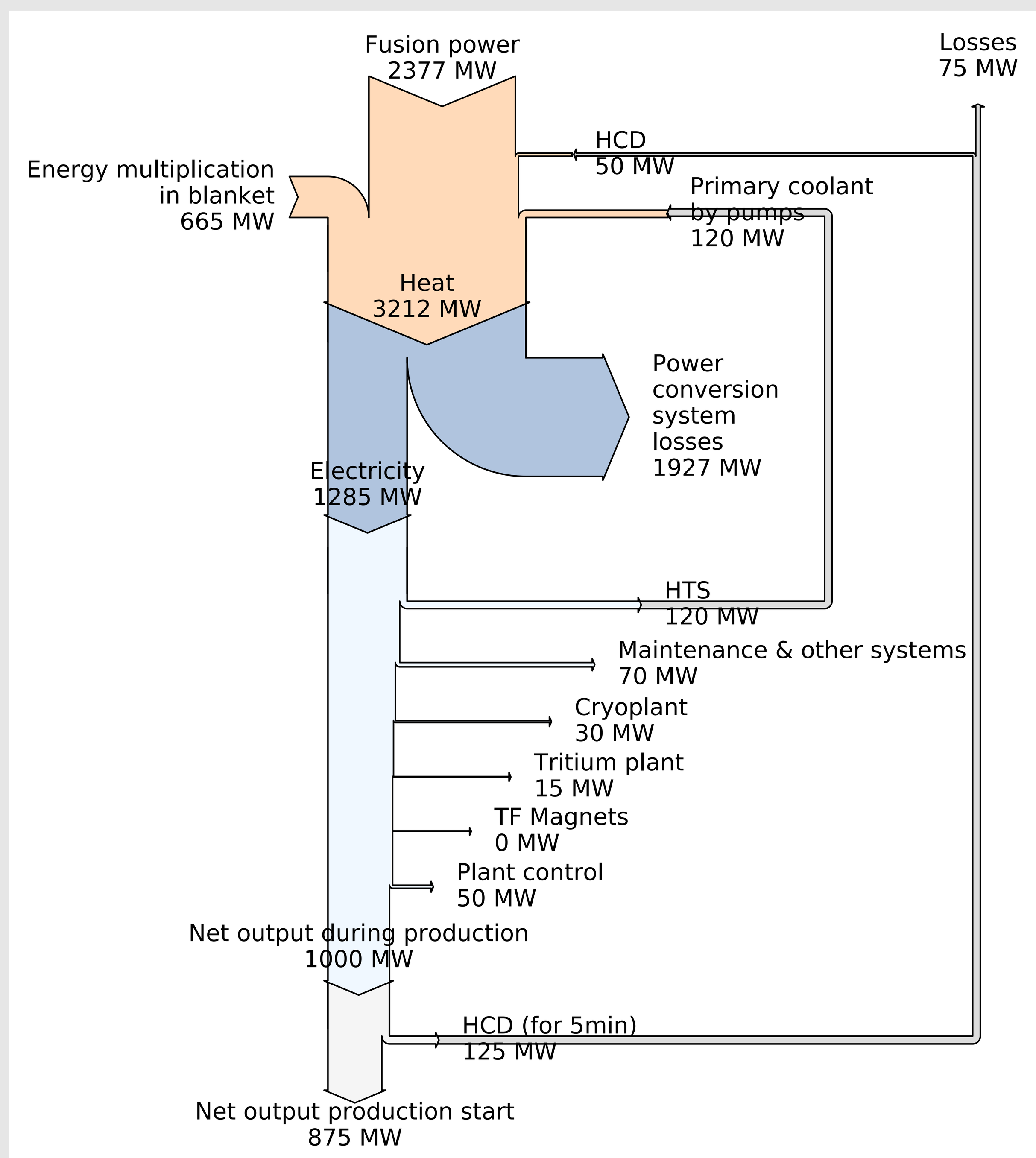


Figure 4: Sankey diagram of stellarator device power balance

Conclusion

- Five operating states with their respective power requirements from an energy system perspective are defined and elaborated, based on the fusion reactor operation and the different auxiliary subsystems which are active during the time.
- Self-consumption of fusion devices accounts for about 13 % in contrast to 2-7 % in conventional power plants. Fusion power balance considers however also the fuel production cycle. From the energy system modeling aspect, operational dynamics shows no tremendous differences to conventional devices when an appropriate thermal energy storage is used together with the flexibility of the power conversion system.
- Future work will include modelling fusion power plants in energy systems as well as investigation of use cases which support their expansion and utilization.

References

[1] European Commission *et al.*, “EU reference scenario 2020: energy, transport and GHG emissions: trends to 2050,” 2021. [Online]. Available: https://data.europa.eu/doi/10.2833/35750
[2] Fuel Cells and Hydrogen 2 Joint Undertaking, „Hydrogen roadmap Europe: A sustainable pathway for the European energy transition,“ 2019.
[3] Technical University of Munich, Chair of Renewable and Sustainable Energy Systems. [Online]. Available: https://www.epe.ed.tum.de/en/ens/research/projects/current-projects/role-of-nuclear-fusion/ (accessed: Sep. 9 2022).
[4] Max Planck Institute for Plasma Physics. [Online]. Available: https://www.ipp.mpg.de/9778/tokamak (accessed: Sep. 9 2022).
[5] Max Planck Institute for Plasma Physics. [Online]. Available: https://www.ipp.mpg.de/9792/stellarator (accessed: Sep. 9 2022).