Policy measures
to drive WBG for end use equipment

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«Wide bandgap devices», «Inverter design», «DC-AC converter», «Reliability», «SiC MOSFET»

Abstract

This paper discusses different potential policy measures to support the WBG uptake in end use equipment. The EU product regulations and specifically the potential PV inverter efficiency requirements, are discussed, serving as an example. Standardisation, in various fields (test methods for reliability and efficiency, rules for environmental footprint, modules and package architecture) and economic support for creating a WBG ecosystem are considered as well. Implementation drivers and barriers are identified through stakeholder interviews highlighting specifically two barriers: knowledge gaps on reliability of WBG and lack of standardised components and product platforms for WBG. The conclusion lists the potential policy measures identified and gives an outlook of the work.

Introduction

The emerging Wide Band Gap (WBG) offers significant opportunities for improved energy efficiency from the rapidly maturing technologies of power electronic devices that are incorporating WBG technologies. PECTA assesses the efficiency benefit of utilizing the WBG technology, to harvest the enormous opportunities [1].

The work presented below assess possible policy measures in relation to the development of WBG technology to suggest ambitious policy measures for selected product applications and within a reasonable timeline.

Several policies, spanning from guidance to targeted product policies with minimum requirements like the European ecodesign, could be relevant and are evaluated. The evaluation is based on current technological state and foreseen development as presented in the “Application Readiness Map” (ARM) which is developed at an earlier stage of the PECTA project [2].

General approach and methodology

The most promising application (concerning the efficiency potential and timing) is being investigated and is presented below. The study explores the feasibility and benefits of the possible policy measures, that so far have only been roughly investigated.

The present work is split in three tasks that explore the potential policy measures, possible product applications, and the timeline for the chosen measures and applications:

- Task 1: Categorization and evaluation of policy measures
- Task 2: Implementation barriers and drivers
- Task 3: Timing of most beneficial policy measures

The project categorizes and investigates potential policy measures according to the IEA Policy

Classification for energy efficiency, and the points below:

- Horizontal measures and initiatives, like component level requirements.
- Vertical measures and initiatives, like efficiency and material requirements, with a focus on a specific application.
- Other aspects or specific concerns that could be considered as relevant for WBG based products.

Policy implementation barriers and drivers are identified through semi-structured interviews with stakeholders from industry, policy makers, test labs and universities.

Finally, the timing of most relevant requirements, their applicability, potential benefits, and limitations are evaluated. Particularly requirements that could be relevant in the ecodesign framework are considered.

During the previous stage of PECTA four product applications were found to be particularly promising for WBG technologies:

- External power supplies (EPS)
- PV inverters
- EV charging stations/DC chargers
- Uninterruptible power supplies (UPS) including for data centres.

After an initial evaluation, PV inverters were selected for further work with the policy mapping.

The motivation for selecting PV inverters is the high potential loss savings (Table 2) and because the European commission is currently assessing and preparing requirement for solar panels and inverters, which means there could be a "window of opportunity" to impact European policy requirements for this application area.

Policy measures and initiatives

The feasibility of policy measures depends on the development stage of the products, which could be classified as:

- Before commercialization (Innovation)
- After build-up / initial commercialization (Penetration enhancement)
- After initial commercialization (Consolidation).

Policy measures could before commercialization focus on supporting research and development, in the initial commercialization stage on promoting the most efficient products on a voluntary basis and when the market is consolidated set mandatory requirements for products.

A crucial parameter to decide on for potential product policies is to consider the following product levels:

- Device level: The component, semiconductor, itself. The more down to single components, the higher potential for horizontal coverage, but also risk of component efficiency comes at the cost of system losses.
- Module level: Meaning more application specific, allowing also targeted regulations.
- Product application level: Appliances or end-user equipment such as PV inverters, EPSs etc.

Stakeholders were asked to comment on this, and the general approach is that requirements should be on product application level. One stakeholder, a component supplier, explained that they had discussed the issue and found that the easiest approach would be requirement on device level, but the impact could be small or non-existing. It is the overall integration of the components that defines how efficient the final product is.

This leads to focus the study on the product application level for which a regulation framework is already in place, as it is in many countries and regions globally. One of the most developed frameworks are the European ecodesign directive and energy labelling regulation.

Ecodesign regulations as WBG driver

The European ecodesign regulations are considered as one of the most important vertical measures, which historically has provided around half of the realized European energy savings and 10 % improved energy efficiency of the products covered by regulations. Ecodesign often apply in tandem with energy label requirements. Where ecodesign applies mandatory minimum energy efficiency requirements aimed for suppliers, energy labelling mandatory information requirements through an easy understandable energy label, will inform consumers and nudge them towards the most efficient products.

The latest development is the extension of the current Ecodesign directive to the new Ecodesign for Sustainable Products Regulation (ESPR) initiative, which will increase the possibilities of ecodesign to handle other resource aspects, to introduce calculations of product environmental footprints (PEF) of products, and potentially an environmental digital product passport (DPP) [11]. This will require development of product specific standards on product categorisation rules (PCR) and material efficiency (ME) aspects. Considering other PECTA studies, the environmental focus and policy measures could be beneficial for WBG products.

Generally, product regulations are most likely to succeed on plug n' play products that are produced in large numbers. Larger products produced for order in smaller numbers are less likely to succeed. For the same reason the ecodesign directive considers a yearly sales number of 200.000 as the minimum limit. Consequently, ecodesign regulations will be relevant for common products that could benefit from WBG technology.

No Ecodesign measures targets WBG technologies specifically, and no ecodesign regulations has so far been written or reviewed to promote the potential benefits from WBG technologies. But ecodesign regulations do cover WBG products in various regulations, including some of the products that are considered for the present work. Table 1 shows WBG relevant regulations being in review process or potential future regulations under development.

Table 1: Ecodesign regulations relevant for WBG products and timing of reviews (EU Commission, winter 2022/23).

Subject and title	Planned adaptation date (indicative)
Ecodesign for PV modules, inverters, and systems, new product group	2023
Electric vehicle chargers, new product group	2026
Ecodesign for external power supplies (EPS), revision	4th quarter 2023
Ecodesign for servers and data storage products, revision	1st quarter 2024
Ecodesign for electric motors and variable speed drives, revision	2025

Table 2 gives an overview of potential savings from new or revised regulations of the prioritized products in the PECTA project as mentioned above in the section "General approach and methodology".

Table 2: Overview of products and their annual saving potentials in the EU by 2023.

Characteristics / Application	Savings [TWh/year]
PV Energy generation Increased production from e.g. higher efficiency DC-AC inverters	11 - 14
Power Supply (AC-DC)	260*
UPS	15
EV Charging Stations	1.4

* Impact estimates from current regulation.

Euro efficiency – a measure to set specific ecodesign requirement on PV inverters

For PV inverters the energy efficiency depends on technology and, apparently, if they serve the utility scale or residential and smaller scale commercial market. The JRC preparatory study [7] finds the following span of Euro efficiency for various product categories:

- Utility scale central inverters with rated capacity up to 4 MW: Euro efficiency 97.5 % – 98.6 %
- String inverters for residential, commercial, or utility scale and rated capacity from a few kW to 166 kW-AC: Euro efficiency 95 – 98.2 %
- Micro inverters for residential and commercial applications (from 0,3 to a few kW rated capacity): Euro efficiency 94 – 97.5 %

Euro efficiency is a measure based on a test method incorporating several part load modes. The development of test standards being able to show “real life” operation is important to demonstrate the benefits of most WBG converter/inverter technologies.

The preparatory study defined three so-called base cases with average products for different sectors. For each of the base cases the study also found improvement potential from the best available technology (BAT) and best not available technology (BNAT). The BAT is defined by the best products that are relatively widely available on the market. BAT is defined by WBG technology. Table 3 shows the Euro efficiency of the different cases and thereby the potential for improvement.

Table 3: Euro efficiency of PV inverters for different applications (extracted from [7]).

Type / Application	Ave-rage	Better EE	WBG
2.5 kW trans-former-less single-phase string inverter	96 %	98 %	99 %
20 kW transformer-less three phase string inverter	97 %	98 %	99 %
1500 kW utility scale central inverter	97 %	98 %	99 %

An interesting note. A small market study was also performed for the current study, and the WBG technology which in 2020 was defined as BNAT seems now, 2023, to be approaching the market with several product launches especially during the last half year.

The current proposal (2022) for minimum requirements of PV inverters is a minimum Euro efficiency of 96% across technologies and capacities.

Market failure

Often energy efficient products are, in-spite of their apparent obvious benefits, not finding their way into the market due to market failures. The reason could be that the market fails to recognize the products, or acts sub-optimal from an economic perspective, e.g., short-term focused on purchase price and not on lifecycle price/total cost of ownership (TCO).

For PV-inverters the picture is mixed. Some product manufacturers informed that when products are compared in tests e.g., at HWT Berlin [10], then only the top products have a chance on the market afterwards. On the other hand, information from a major European whole sales company gives that efficiency is generally ignored. The important factors are price, easy handling (max weight of 25 kg) and quick and easy installation. This company supply the professional installer market for households, small and medium scale commercial and industrial energy installations.

The efficiency values in table 3 for inverters seem to support this, indicating that more professional purchasers have higher focus on efficiency than less professional (utility vs. residential sector).

This underlines the need for appropriate minimum requirements that when set at a higher level than the current proposal will be able to promote WBG technology to avoid market failure. Alternatively, labelling may be a measure to differentiate the best and the average products and pull market towards products including WBG.

Drivers

PECTA already points towards some of the main benefits from WBG technology, and these were indeed confirmed during the stakeholder interviews.

The main technological driver is obviously the potentially low losses with the multiple derived added benefits:

- Less material consumption
- Smaller devices
- Less troubles with over-heating.

With smaller devices the material consumption is smaller (although not yet fully harvested due to higher production waste) and handling might be easier. Alternatively, it is possible to get more power in the same standard modules.

Additionally, a component suppliers informed that further benefits could be [3]:

- More silent operation, for two reasons. First, the lower (heat) loss means potentially smaller, or no, cooling fans. Secondly, reduction of audible noise in magnetics due to the potential operation at other frequency band at higher – non-audible – frequencies. For power drives for compressors e.g., this could help minimizing noise problems of heat pumps.
- Higher thermal conductivity leads to improved heat spread and less risk of hot spots, which improves the lifetime and enables simpler component design.

Consequently, the technologies are being introduced and taken up by the market for some applications where the combination of weight, volume, and efficiency is important.

This is primarily the case for mobile and portable applications, spreading from consumer IT (GaN) to automotive (SiC) applications.

For applications where only one of the parameters, e.g., efficiency is important, the development will be slower or in need of support. One industry representative, however, pointed to PV inverters where (at least for large scale PV systems) the power production is number one parameter, hence market moves towards high-efficiency (SiC) inverters.

So, one conclusion is that product requirements on energy efficiency of PV inverters could be expected to have the largest impact on inverters for residential and small-scale commercial PV's, including the replacement at the end of life of the current stock of PV-inverters.

Barriers

When considering barriers, both interviewees from universities and industries pointed to the historical development of transistors and chips for power electronics and power modules.

The Si IGBT based components, which are todays' standard products, have been developed during the last three decades. All power modules today are developed with the properties of Si IGBT in focus. This goes for the transistors and chips themselves; it goes for all other products categories, frames, and applications they are integrated into; and it goes for the production lines. It has led to the development of current standardized lines of components that fit together from a basic geometrical viewpoint but also when electronic and electrotechnical properties are considered. These components are well known and has through multiple product generations had their real-life performance characteristics, weak-nesses, strengths, safety, EMC, durability etc. tested.

From these considerations, two main barriers for the introduction of WBG products and feasible product policies crystallize:

- Reliability (including knowledge gap).
- Lack of standardized components and product platforms.

Other implementation barriers relate to power quality, capacity limits and production costs, which will be investigated further at a later stage of the project.

Reliability

Generally, industry and some researchers express concern about reliability. Partly from known issues, partly from unknown long-term behaviour, together leading to uncertainties on long-term performance. Furthermore, since the WBG-based components differs from Si-based components, the overall electronics design will also differ.

This potential lack of confidence of performance makes it difficult to set energy efficiency requirements that phase out Si-based components/products, unless there are means to address this through new lifetime/durability test methods, complementary policies such as warranties, etc.

SiC based power electronic is currently entering the automotive sector with increasing pace and during the coming years it will be possible to build on the experience and knowledge gained from there. But products for industrial applications or e.g., PV inverters, cannot always be compared in the case of reliability. The main difference is the use time. The use time of a vehicle can be counted in a few thousands of hours during its entire lifetime. PV inverters and power electronic for industrial applications are operated during full days, or even night and day, and their total operating hours can be counted in tenths or hundreds of thousands of hours.

Relatively high efficiencies (higher than market standard today) can be achieved and with relatively cheap products. However, the risk is that these low-price high-efficiency products fail on other parameters, especially reliability and robustness.

At the same time, standards are not yet developed that can serve as tests for compliance of potential reliability requirements for WBG components.

In conclusion: When considering WBG policies, reliability should be considered together with other parameters. And test standards should be developed for reliability tests. Not just on the device level, but also on the product application level.

Standardized components

If the full benefit from WBG based components should be realized, the overall component architecture and geometry changes, everything known about humidity and temperature resistance, EMC etc. is new or uncertain.

The current architecture is based on standard modules and packages, e.g., power modules where individual components can be changed 1:1 if a better or cheaper component is developed or in case of supply restrictions.

However, this means it is more difficult to gain the full benefit from WBG components, since they are not by nature fully compatible with the existing components and module and package architecture.

Changing from Si IGBT to SiC MOSFET (and GaN) based components – i.e., goodbye to the Si-age and welcome to the WBG age - therefore is not just another one-in-one-out component shift but rather a paradigm shift that has the potential to reshape products and even the industry.

A component supplier considered it to be the most urgent task for (EU) politicians working with industry, to take actions on this issue. In line with the European Chip Act developed when the Covid crisis revealed the European vulnerability regarding computer chip production and supply, a WBG act should be developed and implemented, as soon as possible.

The purpose of such an act should be to develop common standards and product architectures of power modules and systems. At first, the focus could be on SiC products, then later, perhaps after 5 years, on GaN products. The motivation is that power electronics is a central part of many electric and electronic products in household as well as industry. So, it is crucial to prepare the industry for the WBG age to ensure competitiveness and local production of central power components.

In Europe, the EU Commission do support the development of WBG production, for example with the Horizon 2020 REACTION project, which aims to develop a European 200 mm (8 inch) SiC production line [4], and with the Important Project of Common European Interest (‘IPCEI'). which support research, innovation and the first industrial deployment of microelectronics and communication technologies [8]. The support is mainly at the component level, but as explained above it should be considered to supplement with activities on common standards and architectures of power modules and packages as well as integrated product design.

In a WBG roadmap from Power America, a similar approach is suggested, called “Strengthening the Power Electronic Ecosystem” [5].

Conclusion and outlook

This work in progress categorises and evaluates different policy measures that can support increased uptake of WBG technology in end use equipment, with the aim of improving the overall energy efficiency. The evaluation points at product regulation as one of the most promising directions and uses the European ecodesign framework and proposed PV inverter minimum requirements to discuss how ambitious measures can increase WBG application and help to avoid market failure for efficient product with WBG inside.

Semi-structured interviews with stakeholders identified various drivers and barriers for implementation of WBG technology. Besides low energy losses, the drivers include smaller devices and lower material consumption which can be beneficial for WBG technology as product regulations moves towards requirements on product environmental footprint. Among barriers two prominent ones identified are knowledge gaps on reliability of WBG and lack of standardised components and product platforms that can support the WBG ecosystem. Other implementation barriers relate to power quality, capacity limits and production costs, to be investigated further.

Based on the current work there are at least three main policy areas that can support the WBG uptake: Product regulation, standardisation and support of research, innovation and first industrial deployment.

For product regulation, both efficiency and environmental measures can be set to promote WBG for individual end use equipment such as PV inverters, EV chargers, EPSs, UPSs and potentially also motor drives which have a large energy saving potential. Energy efficiency measures must be based on realistic operational profiles, to reflect the advances of WGB technology. For suppliers and end user to gain confidence in new WBG technology, complementary policy measures on lifetime/durability or warranties can be introduced. Energy labelling of products may as well have a role in promoting the most efficient technology.

Standardisation seems to be an important measure for WBG in various ways, both globally and on national/regional scale. The identified needs are standards on:

- Reliability and durability test methodologies. Not just on the device level, but also on the product application level.
- Product categorisation rules (PCR) and material efficiency (ME) aspects of WBG to support the calculation of product environmental footprint (PEF).
- Efficiency test methodologies to support the part load benefits of WBG and to cope with uncertainties when efficiencies are getting high/losses low.
- Product architectures of power modules and systems to gain the full benefit from WBG components when not compatible with the existing Si component, module, and package architecture.

In the field of research, innovation and first industrial deployment, specific economic support should be addressed the whole WBG ecosystem.

The next step in the project will be to conduct more interviews with stakeholders to evaluate, validate and detailing the identified policy measures. When this is done, the idea is to set a timing on when the most beneficial policy measures should potentially be implemented to support energy efficiency (and sustainability) in the best way.

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