1. Each of the applicants has provided proposals for exemptions covering certain Cd QD applications. LE and OSRAM further provided a proposal for a formulation that could cover all three application areas, assuming they are all justified. The various formulations can be viewed in the table below.

Applicant	Initial requested exemption formulation	Proposed joint exemption formulation
Najing	Cadmium selenide in downshifting cadmium-based semiconductor nanocrystal quantum dots for use in display lighting applications (<0.1 µg per mm^2 of display screen area).	
OSRAM	Cadmium in downshifting semiconductor nanocrystal quantum dots directly deposited on LED chips for use in display and projection applications (< 5 µg Cd per mm² of light emitting LED chip surface).	Cadmium in downshifting semiconductor nanocrystal quantum dots - directly deposited on LED semiconductor chips for use in display and projection applications (< 5 µg Cd per mm² of light emitting LED chip surface) - directly deposited on LED semiconductor chips for use in lighting applications of at least CRI 80 (< 1.000 ppm in the luminescent material) - not directly deposited on LED semiconductor chips for use in display and projection applications (< 0.2 µg Cd per mm² of display screen area)
LE	Cadmium (<1000 ppm) in luminescent material for on-chip application on LED semiconductor chips for use in lighting applications of at least CRI 80.	

Please explain if you support that there is a need for an exemption for Cd QD applications:

a. If not please explain why?

b. If yes, please detail which of the proposed formulations you support or provide an alternative proposal, also explaining why you support an exemption and the specific formulation alternative.

Nanosys supports the Najing proposal to renew the exemption based on a 50% reduction in the maximum allowable Cadmium content per display to <0.1µg Cadmium per mm^2 of display screen area.

Cadmium-based Quantum Dot technology remains the most energy efficient wide color gamut display technology on the market by a significant margin. The cadmium exemption is a necessary tool for display makers to achieve recent standards for color gamut performance, such as the BT.2020 UltraHD standard, with high energy efficiency. Displays based on Cadmium Selenide consume 7% to 25% less energy compared to substitute technologies and materials.

According to a study by the independent environmental analysts at SourceOne, ending the exemption would result in a net increase in both Cadmium and green house gasses, such as CO_2, CH_4, and N_2O, in the environment. Therefore, Nanosys believes the total negative environmental, health and consumer safety impacts caused by Cadmium substitution are likely to outweigh the total environmental, health and consumer safety benefits of the continued use of Cadmium in displays.

Technology improvements have enabled a reduction Cadmium content since the exemption was last renewed, enabling the industry to lower the requirement by 50%

from 0.2µg per mm^2 to 0.1µg per mm^2, further reducing the impact of Cadmium's use throughout the consumer display product lifecycle.

In both cases, please provide detailed technical argumentation / evidence in line with the criteria in Art. 5(1)(a) to support your statement.

2. From the information provided by the applicants it can be understood that Cd QDs have various application areas of relevance to the RoHS Directive (displays and lighting) and may be applied in such applications in different configurations (on-edge, on surface, on chip within the LED package and on-chip within a thin layer on top of the chip). As regards the scope of a possible exemption, please provide information to clarify:

    a) Which of the above application areas should be covered by a future exemption;

    Nanosys is not involved in the lighting market nor familiar with the potential benefits of any exemption for that market. Therefore, Nanosys does not offer any opinion on the necessity of on-chip applications with respect to lighting applications. However, based on the data and supporting evidence we are providing here, we believe that a future exemption should cover the display application as this will result in an overall reduction in the amount of GHG and net Cadmium pollution.

    b) For each application area, which configurations should be included in the scope of a future exemption and with which Cd threshold; and

    Nanosys comments are limited to the display application area. Within that area, we do not believe there is any scientific or technical basis to create a scope of specific configurations in a future exemption. The same 0.1µg/mm^2 of display area should apply across all configurations. The display application requires narrow band red, green and blue emitters. To date, the only way in which this has been demonstrated with sufficient reliability and brightness performance has been in a QD film, or in the nomenclature of this exemption, on-surface. On-chip implementations of quantum dots to date have only been able to demonstrate performance with red emitters. Other implementations such as edge-based are no longer in the market due to issues with manufacturability as well as the move of the display industry toward direct backlight architectures.

    c) For how long would an exemption be needed in your opinion in each of these cases (i.e. proposed duration);

    A key factor contributing to the higher power efficiency of CdSe quantum dot implementations is their much narrower FWHM or spectral width. With a wider spectral width, more light energy is out of the target peak wavelength, resulting in more losses as this out of band energy must be reduced by filtering. For on surface applications, we examined the rate of improvement in FWHM for InP (or Cd-free) quantum dot technology from commercially available Samsung QLED TVs and compared that to the FWHM of CdSe based quantum dots today available in 2019 Vizio TV models and others. The results are shown in the table below.

	Cd-free Quantum Dots		CdSe Quantum Dots	
Year	Green FWHM (nm)	Red FWHM (nm)	Green FWHM (nm)	Red FWHM (nm)
2015	41.5	53.0		
2016	40.9	50.0		
2017	40.3	41.0		
2018	39.2	39.8		
2019	36.3	38.2	25.0	25.0

Based purely on this history and without looking into the details in the technical literature regarding the limitations of further reducing the ensemble FWHM of Cd-free quantum dots below 30nm, the extrapolation of when one could expect Cd-free quantum dots to reach a similar FWHM (if no improvements in CdSe QDs were to be made) would be 2022. Until then, CdSe quantum dots would continue to have a better spectral width (FWHM) and therefore higher power efficiency.

Please consider providing information in a tabular format to clarify your views for each case and provide information to support your views.

3. Please provide information concerning available alternatives or developments that may enable reduction, substitution or elimination[2], at present or in the future, of Cd Qds in the various application areas and configurations mentioned in question 2.
   a) In this regard, please provide information as to
      i) Technological improvements which allow reducing the amount of Cd in a specific EEE;

      ii) Substance alternatives;

There are three relevant substance alternatives to consider: Heavy Metal Free Quantum Dots, Conventional Phosphors and Lead Perovskites.

Heavy Metal Free Quantum Dots
Nanosys uses the term "Heavy Metal Free" Quantum Dot to refer to a range of Quantum Dot technologies that contain no heavy metals including Cadmium and Lead. The performance benefits of CdSe based quantum dots are compared to these in this analysis.

Conventional Phosphors
Various red and green-emitting LED phosphor technologies are available today such as KSF. These technologies have poor efficiency for BT.2020 color gamut.

Lead Perovskites
Lead Perovskites are an emerging technology that shows some promise in delivering narrow spectral emission similar to a Quantum Dot. This technology has not shipped in a consumer product to date due to stability issues. Additionally, Lead is not a viable substitute for Cadmium.

iii) Technology alternatives.

Organic Light Emitting Diode (OLED)
OLED technology deployed in consumer televisions fails to deliver BT.2020 color gamut and delivers poor energy performance even at reduced color gamuts. Consequently, Liquid Crystal Displays and QLED displays are projected to remain the dominant display technology for the next decade or more and will therefore have the most impact on the overall efficiency of the installed base of consumer displays.

b) Please provide quantitative data as to application specifications to support your views.

	65" Heavy Metal Free QLED TV	65" CdSe Quantum Dot TV
Cd Content (mg)	0	27.7
Color Gamut	90% BT.2020	90% BT.2020
Full Screen Brightness	600	600
Energy Consumption (Watts)	301	226
EU Cd Emission Saved per year (mg)	0	9.67
EU Cd Emission Saved over 15 years (mg)	0	145.05
Total EU Cd Saved (mg)	0	117.35

4. Please provide information as to research initiatives which are currently looking into the development of possible alternatives for some or all of the application range of Cd Qds in the various application areas and configurations mentioned in question 2.

   a. Please explain what part of the application range is of relevance for such initiatives (in what applications substitution may be possible in the future).

      As noted above, continued research and development of alternative heavy-metal free quantum dots is on-going. Nanosys estimates the industry and academia spend in excess of $25M/year on R&D to develop such materials and that the earliest that such alternatives would be expected to meet the power efficiency of CdSe quantum dots will be 2022.

   b. Please provide a roadmap of such on-going research (phases that are to be carried out), detailing the current status as well as the estimated time needed for further stages.

      The details of the roadmap for these developments is proprietary to the companies and institutions involved in this work and not available to Nanosys to publish.

5. For the various application areas and configurations mentioned in question 2, please provide data as to actual products currently on the market and how this is to develop within the next five years. Please refer in your answer to:

   a) Types of products (lighting products for various purposes, displays of various size and type), also specifying the applied Cd QD configuration;

   The following products utilize Cadmium-containing Quantum Dots and were available in the market over the last 12-18 months. Every product on this list is based on the "on-surface" Quantum Dot configuration. As far as Nanosys is aware, other configurations such as "on-edge" and "on-chip" are not currently available in any shipping display product in the market.

Brand	Model	Type	Size (diagonal inches"
Acer	Iconia 10 Tab	Tablet	10"
Acer	Predator Z271UV	Monitor	27"
Acer	Predator X27	Monitor	27"
Acer	Predator BFG65	Monitor	65"
AOC	AG273UG	Monitor	27"
ASUS	ROG PG27UQ	Monitor	27"
ASUS	ROG Swift PQ35VQ	Monitor	35"
ASUS	ROG PG65	Monitor	65"
Cello	C55SFS4K QLED	TV	55"
Gome	Maxreal 86	TV	86"
Haier	LE55Q9800U	TV	55"
Hisense	75U9	TV	75"
Hisense	65U9	TV	65"
Hisense	75P8	TV	75"
Hisense	65P8	TV	65"
Hisense	55S1U31	TV	55"
Hisense	65S1U31	TV	65"
Hisense	65E9A	TV	65"
Hisense	55E9A	TV	55"
Hisense	ULED XD	TV	65"
Hisense	Sonic One	TV	65"
Hisense	H9F	TV	55"
Hisense	H9F	TV	65"
Hisense	U9F	TV	75"
JVC	JVC 65	TV	65"
JVC	JVC 55	TV	55"
Philips	43M6VBRAB	Monitor	43"
Phillips	65-9603	TV	65"
Phillips	55-9603	TV	55"

Polaroid	PDK55U	TV	55"
PPTV	65Q900	TV	65"
TCL	X6 QLED	TV	85"
TCL	55X5C	TV	55"
TCL	65X5C	TV	65"
TCL	55X6	TV	55"
TCL	65X6	TV	65"
TCL	65Q960C	TV	65"
TCL	55Q960C	TV	55"
TCL	75X8	TV	75"
TCL	65X8	TV	65"
TCL	55X8	TV	55"
TCL	75X8	TV	75"
TCL	65X8	TV	65"
TCL	55X8	TV	55"
TCL	X10 FIBA	TV	75"
Vestel	QDTV65	TV	65"
Vizio	P-Quantum	TV	65"
Vizio	43 M-Series Quantum M7	TV	43"
Vizio	50 M-Series Quantum M7	TV	50"
Vizio	55 M-Series Quantum M7	TV	55"
Vizio	65 M-Series Quantum M7	TV	65"
Vizio	50 M-Series Quantum M8	TV	55"
Vizio	55 M-Series Quantum M8	TV	55"
Vizio	65 M-Series Quantum M8	TV	65"
Vizio	65 P-Series Quantum P9	TV	65"
Vizio	75 P-Series Quantum P9	TV	75"
Vizio	65 P-Series Quantum X	TV	65"
Vizio	75 P-Series Quantum X	TV	75"
Vizio	85 P-Series Quantum X	TV	75"

According to Nanosys internal data, approximately 1.37 million Quantum Dot TVs will ship into the EU market in 2019. This number is projected to grow rapidly over the next 5 years with over 50 million Cd-based Quantum Dot TV devices sold in the EU market alone during 2020 through 2025.

Due to the larger screen size and power requirements of consumer TVs we project that TVs will have the largest impact in the EU and have focused our responses on that segment in this questionnaire. However, growth in Quantum Dots in mobile devices such as tablets and PC monitors are expected to be the even higher over the next five years.

Nanosys estimates over 150,000 Quantum Dot monitors will be sold in the EU during 2019, mostly in the premium graphic design and gaming segments.

However, this number is expected to grow rapidly over the next 5 years with as many as 15 million monitors sold during 2020 through 2025.

b) The amount of Cd contained within the product;

The amount of Cd contained within a display can vary based on a few factors such as target color gamut, white point, and overall display stack design. Typical Cd content in consumer displays ranges from 0.025ug/mm2 to 0.1 ug/m2. In the attached study by SourceOne, we used a value of 0.02374ug/mm2 which is representative of the top-performing Cd based QD TVs on the market.

c) Alternative products of the same type that are Cd free and that provide similar performance in terms of colour output (CRI, colour gamut, etc. as relevant to the application area) energy efficiency.

No other technology on the market delivers similar performance in terms of color output as measured in industry standard BT.2020 color gamut coverage. While it is possible to improve the color gamut coverage of substitute materials and technologies, doing so comes at a significant cost in terms of energy efficiency.

6. For the various application areas and configurations mentioned in question 2, please provide information to allow a comparison of technologies (within the CdQD portfolio and beyond) in relation to the performance they provide so as to support the views expressed in earlier answers (support of the exemption and its various scope options or objection to an exemption):

   a. Please refer in your answers to the parameters of relevance for this comparison (including as a minimum colour output parameters, energy consumption and energy efficiency parameters) and provide quantitative data to allow a comparison of relevant products.

Content-Driven Experiences

The trend in consumer displays in 2019 is towards wider color gamuts and High Dynamic Range (HDR) with high peak luminance. This trend is driven by the increasing availability of content optimized for these features. Wide color gamut, HDR displays are supported by a growing ecosystem of content sources that offer wide color gamut/HDR content that can only be full appreciated on displays with these features.

In 2019 consumers have access to a large, and rapidly growing, selection of wide color gamut content from content distribution networks such as Netflix, Amazon Prime as well as live event broadcasts including the upcoming 2020 Olympics and World Cup events. According to HD Report[1] over 720 wide color gamut TV series and movies available to watch online or by UltraHD BluRay disc.

There are three key parameters to consider in making performance comparisons for Cd QD displays: Color Gamut, Luminance and Power Consumption. Note that

[1] HD-Report, link: https://hd-report.com/, accessed 5/10/19.

we have not considered parameters for measuring lighting applications. The following parameters are relevant to displays of all types and configurations.

Color Gamut

The Color Gamut of a display is a measure of the range of colors it can reproduce. Color Gamut is expressed as an area, representing the amount of area covered on a CIE chromaticity chart between the red, green and blue primaries of the display.[2] Displays with a larger or "wider" color gamut area are able to more closely match the range of colors found in nature, delivering a more lifelike display experience.

A display's color gamut has a marked impact on energy consumption. Displays with wider color gamuts tend to consumer more power than displays with narrower color gamuts. Therefore, it is important to control for color gamut when making comparisons between display materials and technologies of different types.

The current trend in the marketplace is towards wider color gamuts. When the Oeko Institute last reviewed the Cadmium exemption for displays, all consumer TVs on the market relied on the BT.709, or sRGB, color gamut. Since that time, the industry has begun a transition to the much wider BT.2020 color gamut as part of a broader push towards displays with more lifelike image quality including higher resolution, luminance and color.

The BT.2020 color gamut parameters are defined by the International Telecommunication Union). BT.2020 is over 70% larger than the rec.709 gamut and can accurately reproduce 99.9% of the range of surface colors found in the natural world[3]. Today, a wide range of consumer electronics devices and professionally produced content support the standard. This includes TVs, Monitors, Smartphones and UltraHD BluRay players.

The best displays on the market in 2019 are capable of reproducing approximately 80-85% of the BT.2020 color gamut. However, beginning in 2020, based on feedback from display manufacturers and their internal roadmaps, we expect a move to greater than 90% of BT.2020. Therefore, when looking at display performance for the period from 2020 through 2025, >90% BT.2020 color gamut should be considered.

Luminance

In addition to wide color gamut, modern displays are tasked with reproducing a wider range of luminance in order to create a lifelike experience. Like color gamut, luminance is directly correlated to power consumption and should also be controlled for when making display energy consumption comparisons.

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[2] Commission Internationale de l'Eclairage (CIE), Colorimetry (Second Edition), *Publication CIE 15.2*, Bureau Central de la CIE, 1986.

[3] TFT Centeral, "*The Pointer's Gamut The coverage of real surface colors by RGB color spaces and wide gamut displays*," Kid Jansen, Updated 19 February 2014 https://www.tftcentral.co.uk/articles/pointers_gamut.htm

The ITU recommends certain minimum standards for HDR display performance. According to the ITU's recommendation "BT.2100 Image parameter values for high dynamic range television for use in production and international programme exchange," the "peak luminance" of an HDR display should be greater than or equal to 1,000 nits.

Peak luminance refers to a display's abililty to reproduce high luminance in a small area of the display. Typical value for peak luminance measurements look at the peak luminance generated over a 10% area of the display.

The best performing displays on the market in 2019 are able to produce over 1,000 nits luminance at 100% full screen white and over 3,000 nits peak luminance for 10% white area peaks.

Power Consumption
Power consumption is the most important metric for this study. Consumer adoption of Wide Color Gamut and HDR features should not come at a cost to the environment. In evaluating display performance, it is critical to look at the impact of these new features on display power consumption.

Cadmium Quantum Dots remain an important tool for display makers to deliver wide color gamut, high peak luminance displays without increasing display power consumption.

b. Please specify the relevant standards or methods that are considered as acceptable for measuring and comparing the various parameters mentioned in a.

Nanosys recommends the following standards and methods for display performance comparisons.

Relative Color Gamut Area
When measuring display color performance, it is important to look at how a display performs relative to a standard color gamut. Nanosys measures color gamut area relative to the UltraHD BT.2020 color gamut. BT.2020 color gamut parameters are defined by the International Telecommunication Union in ITU-R BT.2020-2.

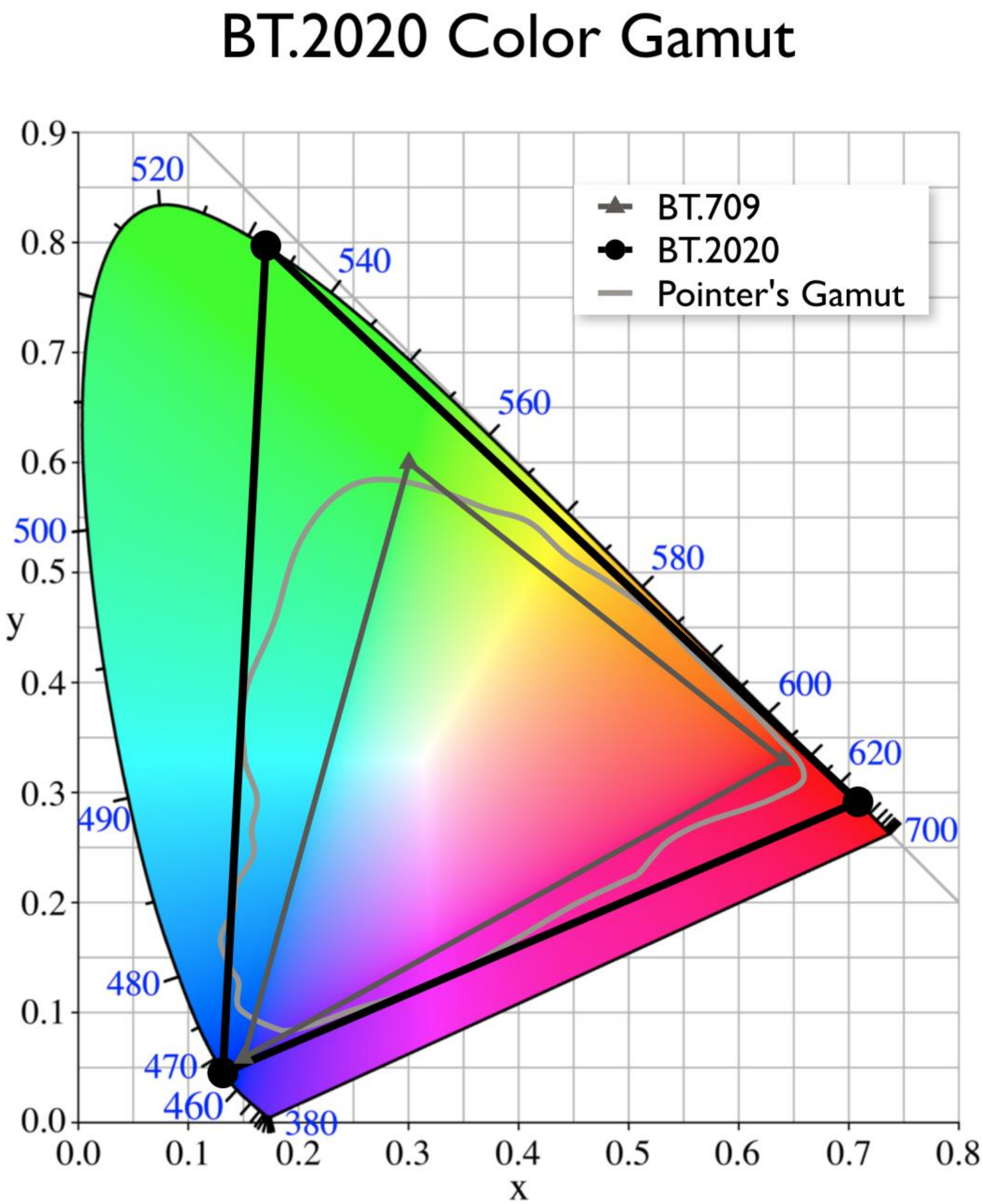

Figure 1: BT.2020 color gamut compared to BT.709 and Pointer's Gamut area in CIE 1931

When making Color Gamut Area comparisons Nanosys utilizes the International Committee for Display Metrology's (ICDM) International Display Measurements

Standard (IDMS), version 1.03b method described in section 5.18.1 "Relative Gamut Area."[4]

Luminance
The display under test must be capable of delivering an "HDR" experience. There are a number of standards and recommendations that set the bar for "HDR" performance:

- International Telecommunications Union ITU-R BT.2100: ≥1,000 nits
- UltraHD Alliance Premium Certified Specification: ≥1,000 nits[5]
- VESA HDR1000 Certified Specifications: ≥1,000 nits[6]

Measurement methods:

- IDMS: Section 5.3, Full Screen White[3]
- IEC 62087-3:2015 section 3.1.11[7]

Power Consumption
Nanosys uses IDMS recommendations for power consumption measurements. Here, it is important to isolate display power consumption from overall device power consumption.

Measurement method:

- IDMS Section 14.1.1 on Power Consumption[3]

7. As part of the evaluation, socio-economic impacts shall also be compiled and evaluated. The applicants have provided various data and information in this respect. If possible, please provide additional information where more detailed quantification is possible concerning:

a) The volume of EEE concerned;

Nanosys estimates that over 50 million Quantum Dot TVs and 15 million monitors will be sold in the EU over the next 5 years, from 2020 through 2025.

b) Amount of Cd to be avoided should the exemption not be granted;

Nanosys has partnered with SourceOne, a well recognized expert in environmental consulting to model the impact of this exemption. Nanosys is submitting a report authored by SourceOne as a supporting document to this

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[4] International Committee for Display Metrology, "Information Display Measurements Standard", 2012.
[5] UltraHD Alliance, "UHD Alliance Defines Premium Home Entertainment Experience", link: https://www.businesswire.com/news/home/20160104006605/en/UHD-Alliance-Defines-Premium-Home-Entertainment-Experience, accessed 5/10/19.
[6] VESA, "Summary of DisplayHDR Specs," link: https://displayhdr.org/performance-criteria/, accessed 5/10/19.
[7] IEC 62087-2:2015, **"**Audio, video, and related equipment - Determination of power consumption - Part 2: Signals and media," link: https://webstore.iec.ch/publication/22582, accessed 5/10/19.

submission. According to this report, Cadmium would increase in the environment should the exemption not be granted. Using the attached report by SourceOne on energy consumption, it can be calculated that ~114 TWh of electricity will be saved over the lifetime of those TVs by the use of Cadmium-containing Quantum Dots. This reduction in electricity consumption eliminates Cd air emissions by 9.67mg per TV. Over the next 5 years through 2025, this increase would lead to a net impact of nearly 35.8 million metric tons of additional environmental GHG releases.

c) Estimations as to possible additional waste to be generated through a forced phase-out (if relevant);

Not relevant

d) Estimation of impacts on employment in total, in the EU and outside the EU, should the exemption not be granted. Please detail the main sectors in which possible impacts are expected – manufacturers, supply chain, retail, etc.

The impact of the reduction in GHG released by the allowance of this exemption is equivalent to that produced by 7.8 million automobiles in a year. It could therefore be argued that not granting this exemption would be the equivalent of adding 7.8 million cars to the roads of Europe. The net effect of this increase in pollution on employment, human health, climate change and the like would be significant. Nanosys lacks the expertise to express this in the terms of the question however.

e) Please estimate additional costs associated with a forced substitution should the exemption not be granted, and how this is divided between various sectors (e.g. private, public, industry: manufacturers, suppliers, retailers).

Any forced substitution would result in additional costs for electricity production (approximately 114 TWh over the life of the products) as well as the associated impact costs of the accompanying GHG releases.

In case parts of your contribution are confidential, please provide your contribution in two versions (public /confidential). Please also note, however, that requested exemptions cannot be granted based on confidential information!

Finally, please do not forget to provide your contact details (Name, Organisation, e-mail and phone number) so that Oeko-Institut/Fraunhofer IZM can contact you in case there are questions concerning your contribution.