WATER SCARCITY FOOTPRINT OF PALM OIL BASED RENEWABLE DIESEL

Final report

November 2016

LAPPEENRANTA UNIVERSITY OF TECHNOLOGY

This study is a subcontracting work in the Sustainable Bioenergy Solutions for Tomorrow (BEST) research program coordinated by FIBIC Ltd. and CLEEN Ltd. with funding from the Finnish Funding Agency for Technology and Innovation, Tekes.

Participants

- Heli Kasurinen, LUT
- Risto Soukka, LUT
- Annamari Enström, Neste
- Sari Kuusisto, Neste
- Denny Turino, GAR
- Serafina Rahayu, GAR
- Haskarlianus Pasang, GAR

Outline

Introduction

Background (1/2)

- The global production volume of palm oil is the largest of all vegetable oils, accounting for over 50 million tonnes in 2010 (Lamers et al., 2013).
- Which feedstock is available for renewable diesel or biodiesel (biofuel) production highly depends on the geographic location. Indonesia and Malaysia provide palm oil feedstock for biofuel production, whereas the US, Brazil and Argentina use soybean oil, and the EU has traditionally utilized rapeseed oil. However, recently, the share of soybean and palm oil has increased in the EU biofuel production. (Lamers et al., 2013; Milazzo et al., 2013a, 2013b.)
- Palm oil is a well-known and widely used raw material of biofuel. The top producer of oil palm worldwide was Indonesia with a production volume of 26,9 million tonnes in 2013. The second largest producer, Malaysia, accounted for 19,2 million tonnes of oil palm in 2013. In Indonesia, the annual growth rate of the production was 11 % from 1993 to 2013. (FAOSTAT, 2015.) In 2013, Indonesia produced 26,9 tonnes of palm oil, which can be utilized for biofuel as well as food production, together with 3 million tonnes of oil palm kernels, which can be utilized as raw material for palm kernel oil (FAOSTAT, 2015; WWF, 2015e). Indonesia was selected as the production location of palm oil in this study.

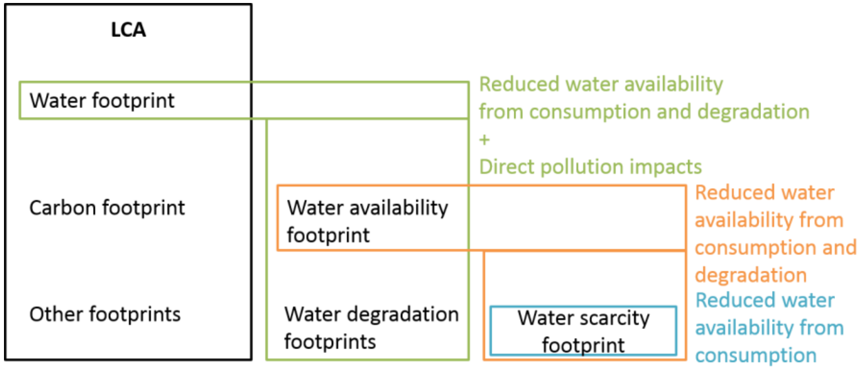
Background (2/2)

- Greenhouse gas emissions and energy balance have long been constantly included in the assessment of bioenergy systems' sustainability (Buchholz et al., 2009; Cherubini & Strømman, 2011).
- As the demand for biofuels increases in Europe, largely due to renewable energy targets (2009/28/EC), more holistic sustainability assessments of different bio-based raw materials, raw material production locations and biofuel production pathways increase in importance. Holisticity in bioenergy assessments is strongly advocated by the scientific community (Buchholz et al. 2007; Sheehan 2009; Dale et al. 2013). Assessment of water-related sustainability is an important addition to traditionally greenhouse gas- and energy balance focused sustainability studies. Utilization of water resources has especially local significance.
- More recently, water security – water consumption and degradation impacts – has become a rising trend in business sustainability assessment (CDP 2015). Water has become a key issue at board and executive level in many companies.
  - 70% identified water as substantial business risk
  - 64% of reported risks expected to impact now or within the next five years

  (CDP Water Disclosure questionnaire 2013 answered by 184 Global 500 corporations from various sectors)
- Several tools for the assessment of the sustainability aspects of water use have emerged. The ISO 14046 standard on water footprinting was published in 2014.
- Water related impacts can be relevant for business in several ways, causing, for example, risks of higher operating costs, reduction in revenue, closure of operations, production and water supply disruption, permitting delays, and property and brand damage (CDP 2015).
- Business risks could be divided into four categories: physical, reputational, regulatory and financial risks.
- Simultaneously with risk management, business operators strive to enhancing their brand, decreasing costs and increasing profit.

Objective

- The objective of this study is to conduct a water scarcity footprint assessment according to the ISO 14046 for a production chain from cradle to gate, in which oil palm is cultivated and crude palm oil (CPO) is produced in Central Kalimantan, Indonesia and further refined in Rotterdam, the Netherlands into renewable diesel.
- A mixture of vegetable, waste and residue based raw materials are used in the renewable diesel refinery, but for the case study all feed was presumed to be crude palm oil.

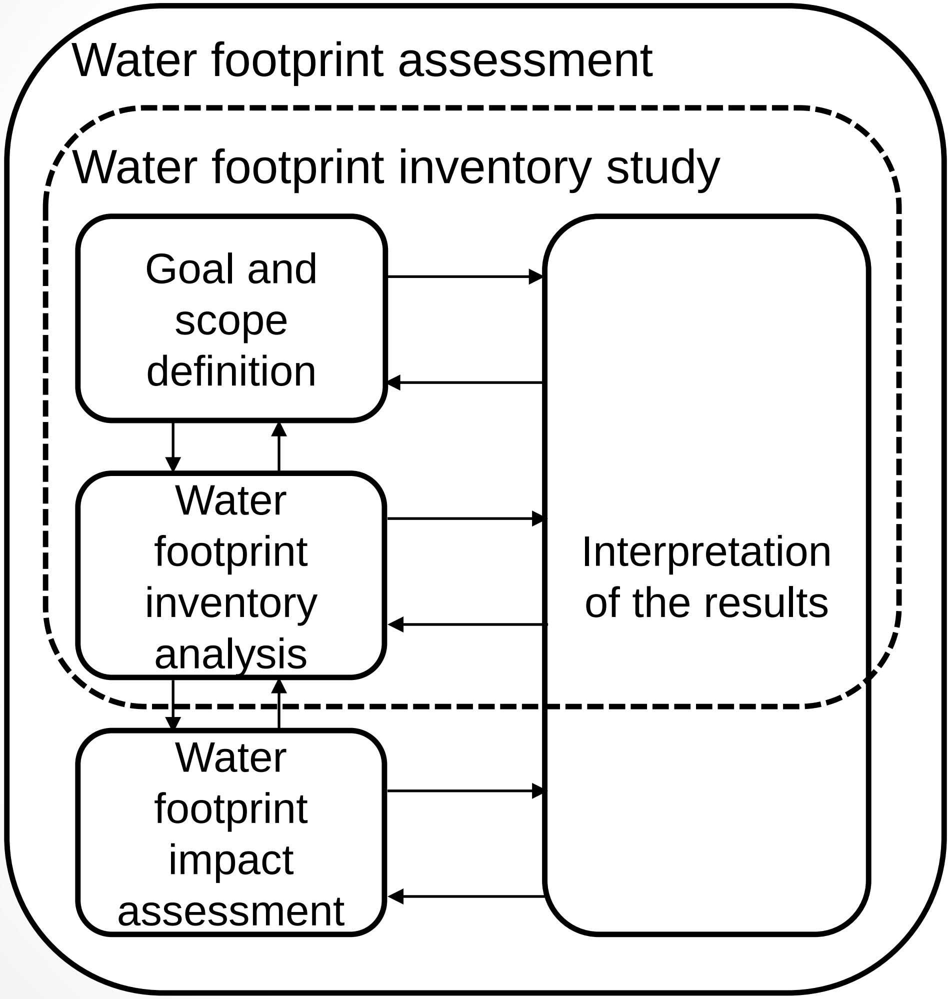


Relations of water footprints (adapted from Boulay & Vionnet 2014; Boulay 2015)

Methods

- The water scarcity footprint is calculated according to the standard ISO 14046 Water footprint.
- Two alternative methods are used for the characterisation of the water scarcity footprint
  - Available Water Remaining (AWaRE) method (Boulay et al., 2015; WULCA, 2016)
  - Water Stress Index (WSI) method (Ridoutt and Pfister, 2013)
- The calculations for CPO production are done both based on literature data and based on actual data. The calculations for renewable diesel refinery are done based on actual data.
- The functional unit is 1 kg of renewable diesel produced.
- Mass allocation is used for palm oil mill and energy allocation (lower heating value) for renewable diesel refinery.
- All indirect water flows and transportations are excluded.

Methods: The phases of a water footprint assessment according to ISO 14046



WSI method (2013)

$$WSF = \sum_i \frac{CWU_i \cdot WSI_i}{WSI_{global}}$$

WSF = Water Scarcity Footprint ("amount of water as if it was consumed globally")

CWU_i = Consumptive Water Use in region i (blue water)

WSI_i = regional Water Stress Index (the WSIs at watershed level found in Google Earth (Pfister et al. 2009) were used)

WSI_{global} = global average Water Stress Index: value 0,602 (Ridoutt & Pfister 2013; Thylmann 2014) or 0,44 (Pfister & Bayer 2014)

(Ridoutt & Pfister 2013; Thylmann 2014.)

AWaRe method (2015)

$$WSF = CWU \cdot AWaRe = CWU \cdot \frac{1}{Unused\ water\ remaining}$$

WSF = Water Scarcity Footprint (“relative user deprivation potential”) [$m^3_{world\ eq}$]

CWU = Consumptive Water Use [$m^3_{region\ i}$]

Unused water remaining = AMD_{region}/AMD_{world} [$m^3_{region\ i}/m^3_{world}$]

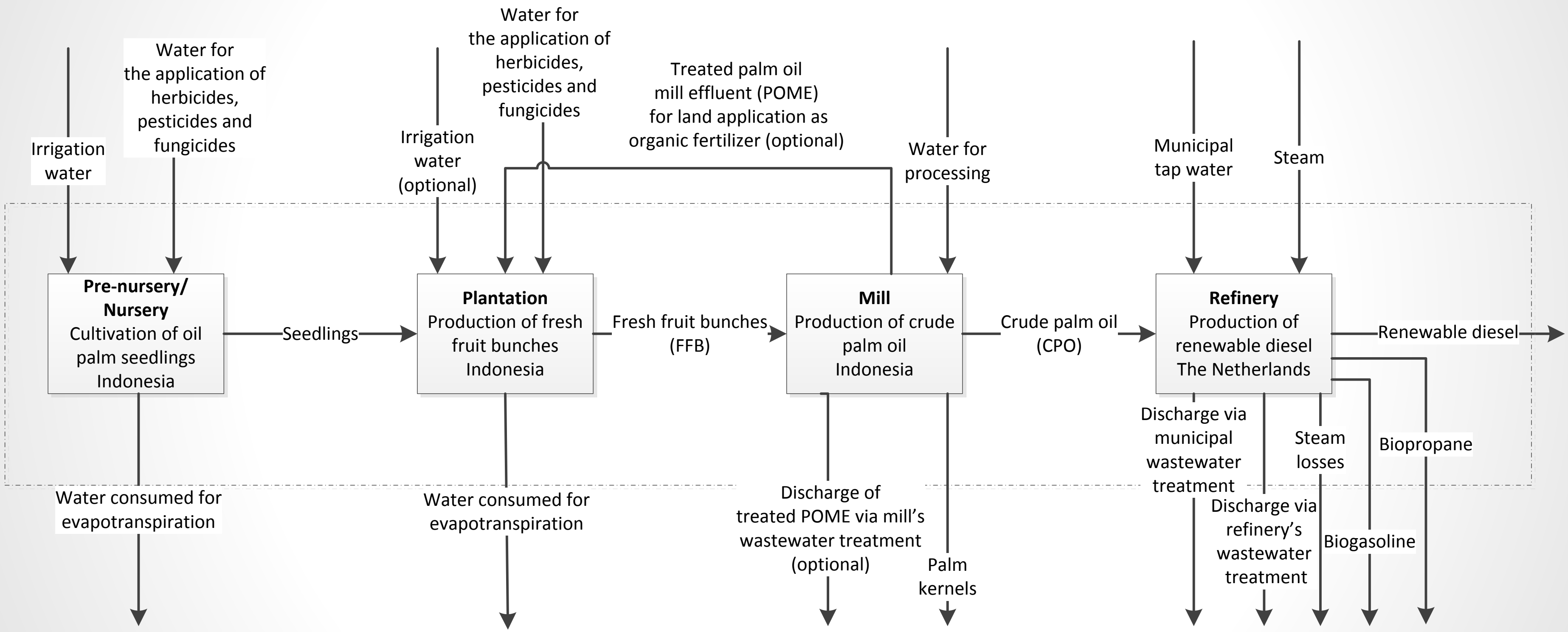
AMD = Availability Minus Demand

AMD_{world} = 0,0136 $m^3_{world}\ m^{-2}\ month^{-1}$

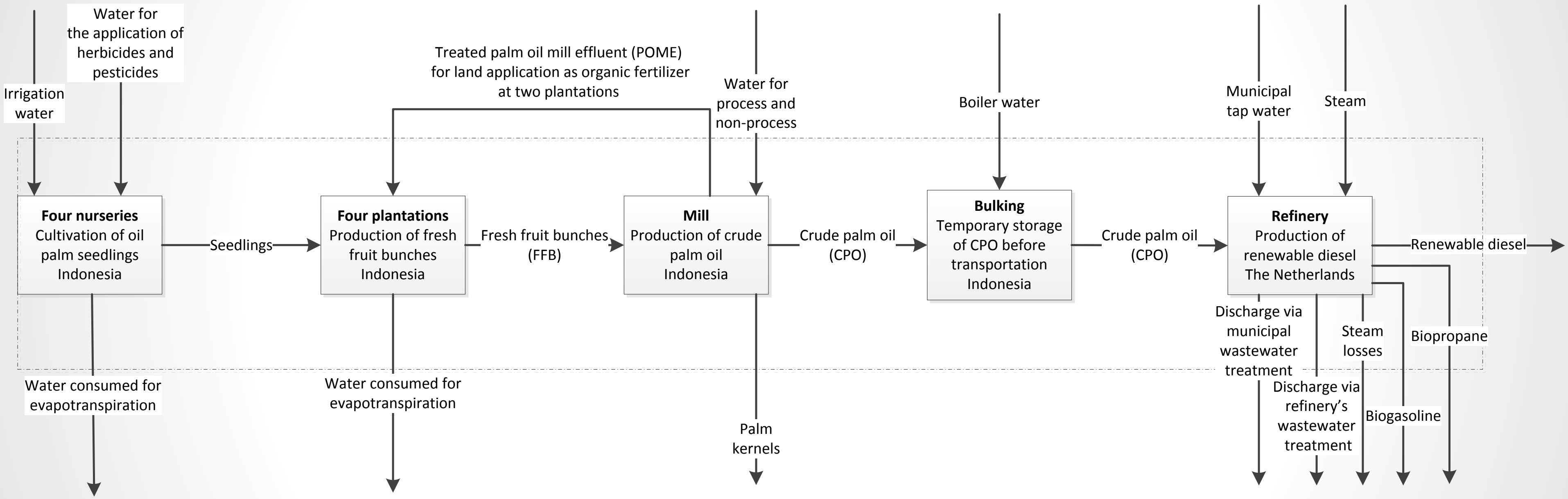
1/Unused water remaining = AWaRe = Available Water Remaining

(Boulay 2015; Boulay et al. 2015b; WULCA 2016.)

Unit processes and water balances (literature)



Unit processes and water balances (actual data)



Water inventory results

Blue water consumption

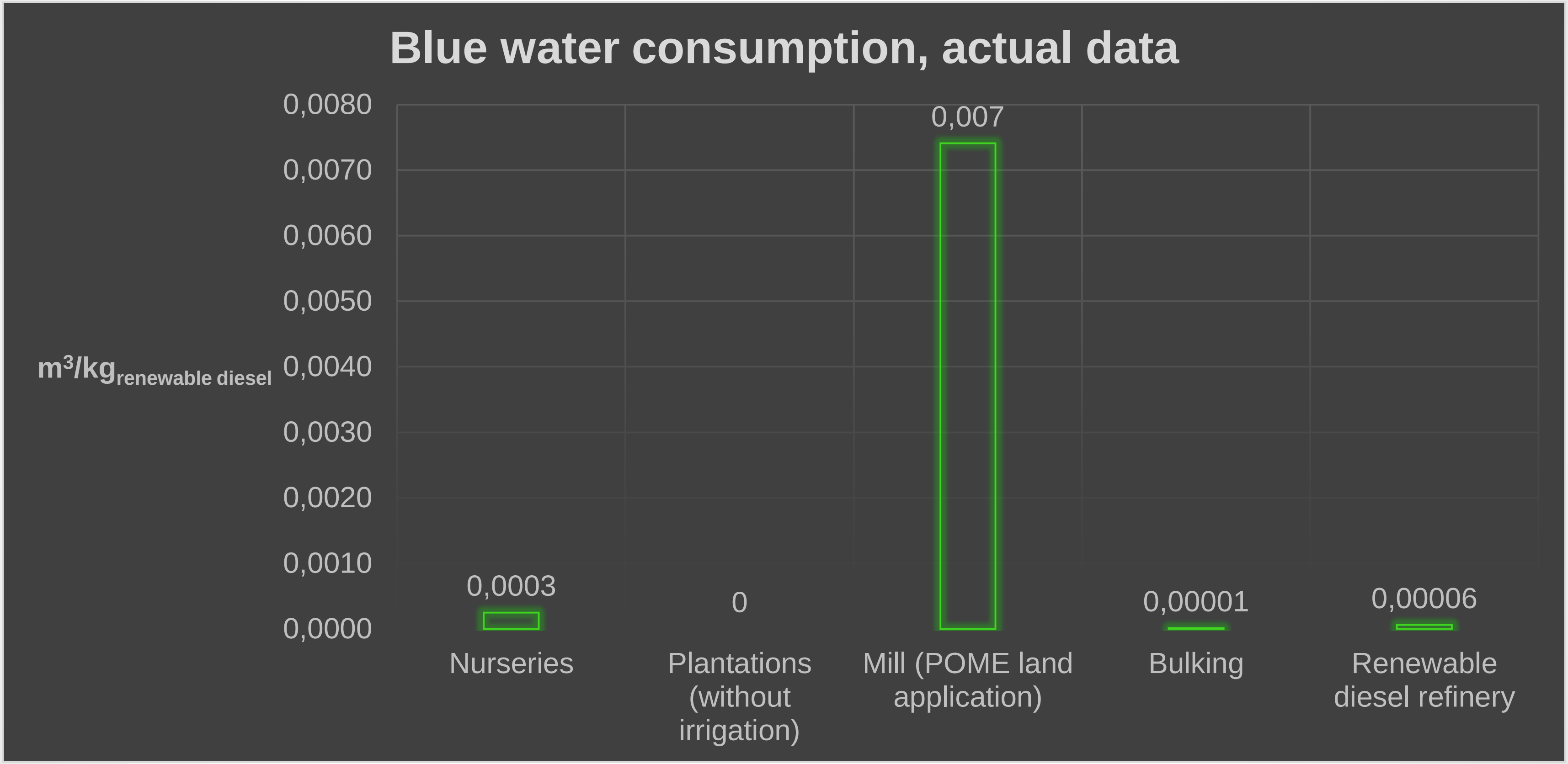
Comparison of inventory data

Stage	Description of water consumption	Water consumption in m^3/kg renewable diesel: Literature data		Water consumption in m^3/kg renewable diesel: Actual data
Pre-nursery	Irrigation	0,00006		-
	Blue water consumption	0,00006		-
Nursery	Irrigation	0,0005		0,0002
	Application of herbicides	0,00000006		0,00002
	Application of pesticides			0,000005
	Application of fungicides			
	Blue water consumption	0,0006		0,0003
Plantation	Irrigation	0,8		0
	Application of herbicides, pesticides and fungicides	0,0008		0
	Water for offices and housing complex (excluded)	-		0,03
	Blue water consumption (1st column with irrigation, 2nd column without irrigation)	0,8	0,0008	0
Mill	Water for process (1st column without dilution, 2nd column with dilution)	0,003	0,006	-
	Water for process + non-process	-		0,007
	Blue water consumption (literature: 1st column without dilution, 2nd column with dilution; in the case that POME is returned to the same water system that supplies the mill with raw water)	0,0008	0,003	-
	Blue water consumption (literature: 1st column without dilution, 2nd column with dilution; literature and actual data: in the case that POME is used for land application at the plantation(s))	0,003	0,006	0,007
Bulking	Treated Water from Mills for process = Boiler water consumption	-		0,00001
	Water consumption for Office+Lab	-		0,00000003
	Blue water consumption	-		0,00001
Renewable diesel refinery	Blue water consumption	-		0,00006

Example: water consumption at the plantation

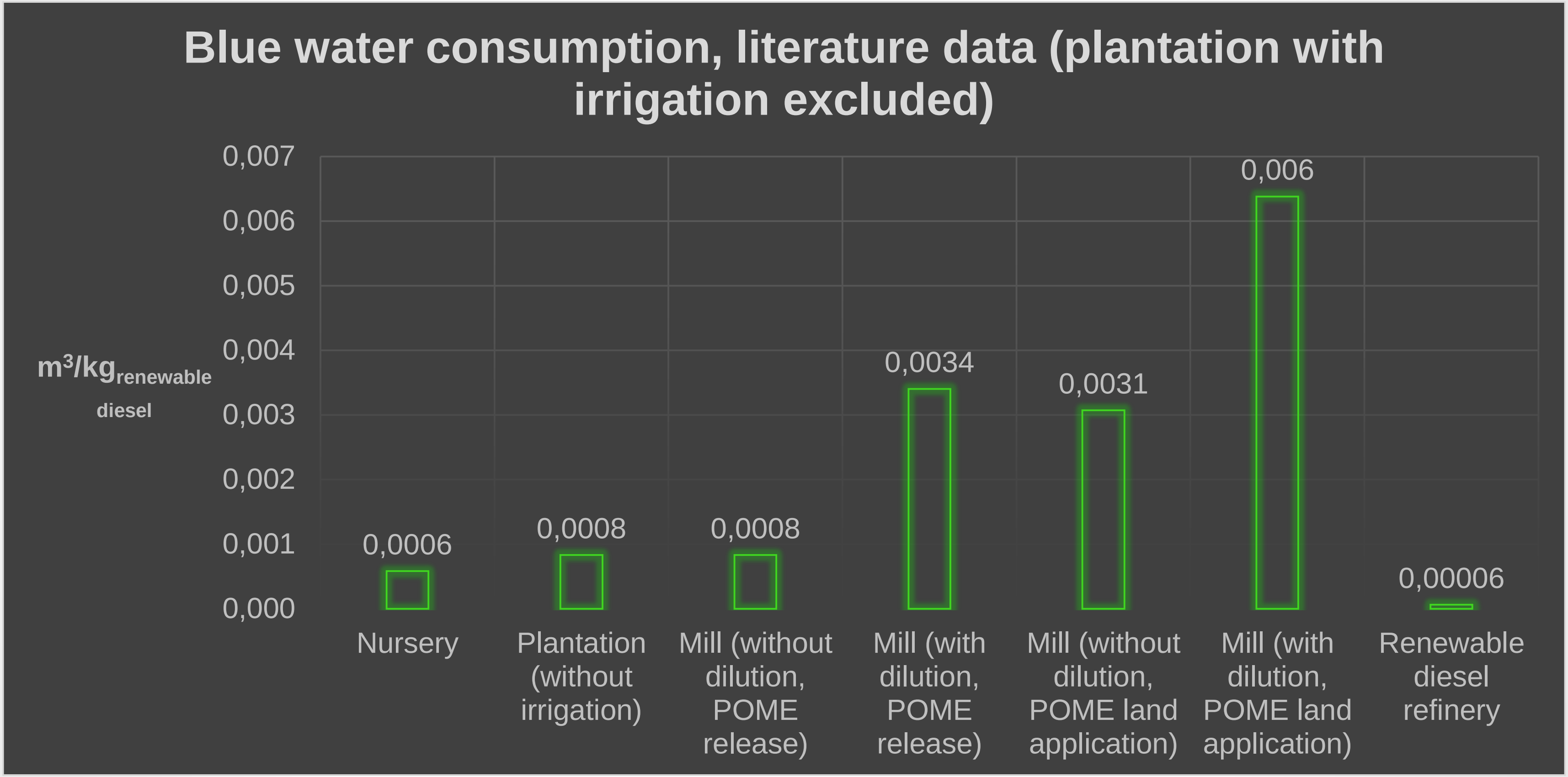
Blue water consumption at the plantation	**m^3/t_{FFB}**	**Region**	**Reference**
Irrigation + application of herbicides	60	Thailand	Suttayakul et al. 2016
Irrigation + application of herbicides	142	Thailand	Suttayakul et al. 2016
Irrigation + application of herbicides	140	Thailand	Suttayakul et al. 2016
Irrigation + application of herbicides	492	Thailand	Suttayakul et al. 2016
Without irrigation	3,4	Malaysia	Zulkifli et al. 2014; Vijaya et al. 2010
Irrigation	0,0	Indonesia	Egeskog & Scheer 2016
Irrigation	0,0	Indonesia	Actual data
Offices, housing complex (Plantation 1), excluded	1,4	Indonesia	Actual data
Offices, housing complex (Plantation 2), excluded	2,0	Indonesia	Actual data
Offices, housing complex (Plantation 3), excluded	1,6	Indonesia	Actual data
Offices, housing complex (Plantation 4), excluded	2,1	Indonesia	Actual data

Blue water consumption (actual data)



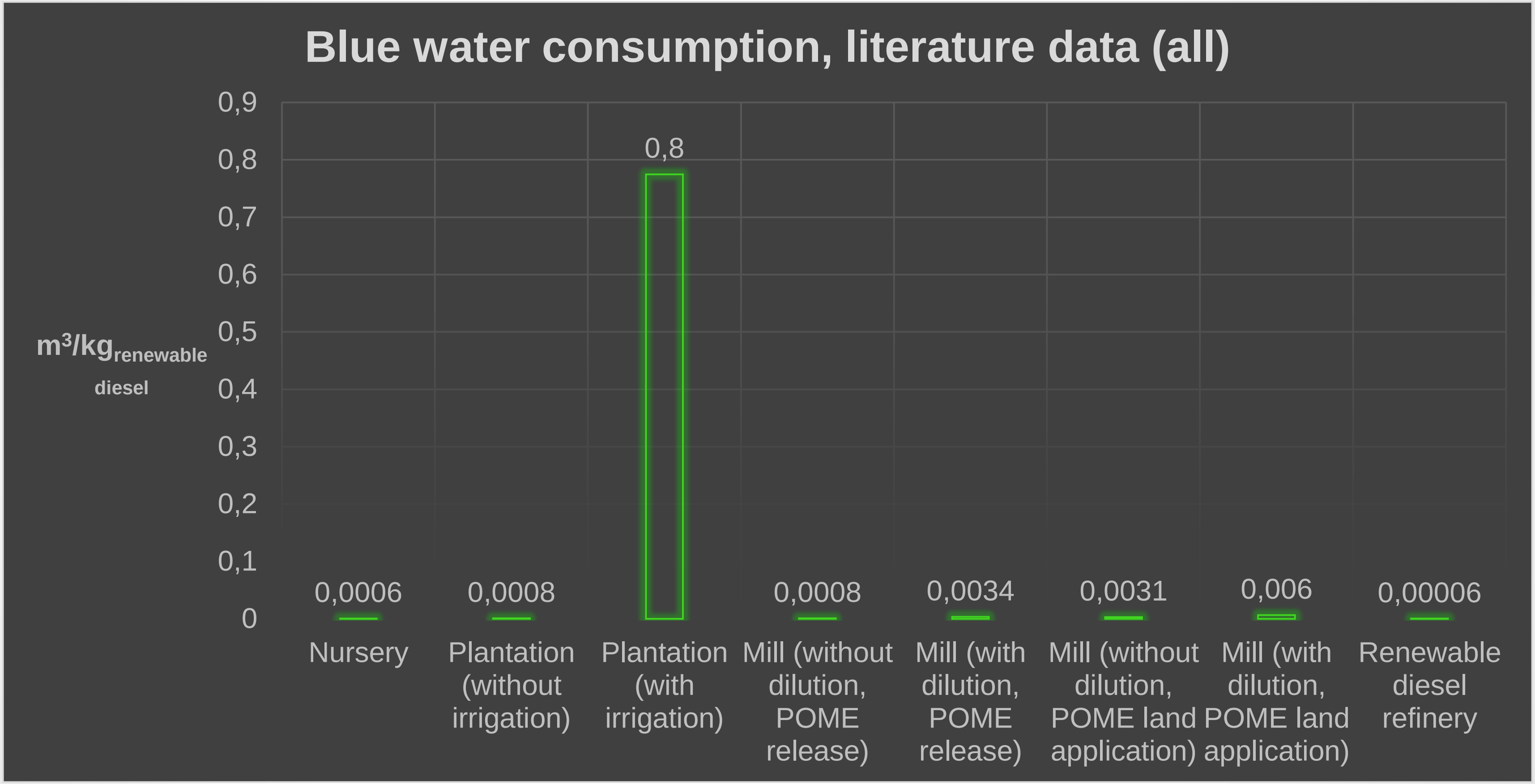
POME land application = POME is applied as irrigation water/fertilizer at the plantation.

Blue water consumption (literature)



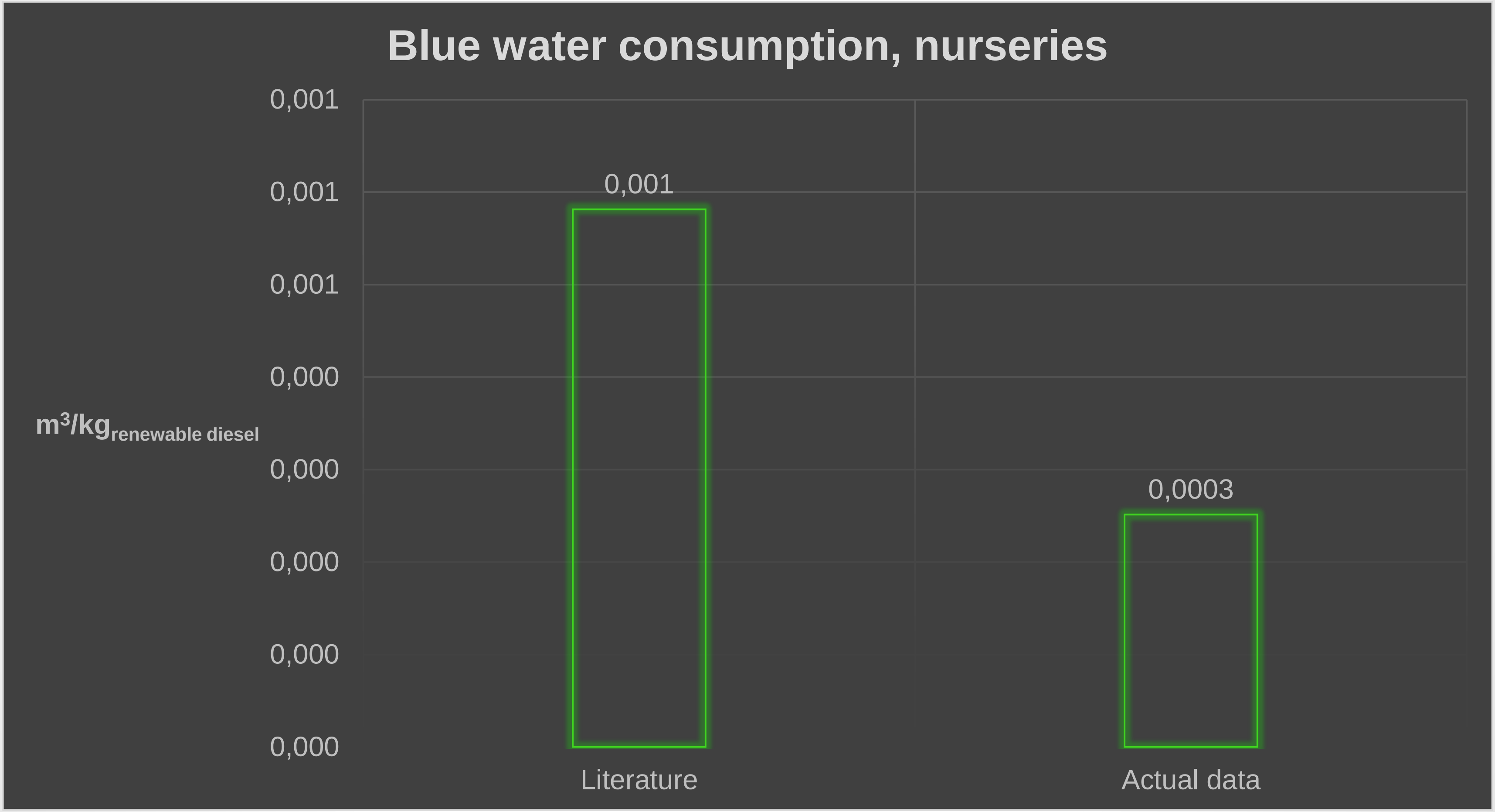
Blue water consumption of the plantation without irrigation equals water consumption for the application of herbicides and pesticides.
POME release = POME is returned to the same water system that supplies the mill with raw water.
POME land application = POME is applied as irrigation water/fertilizer at the plantation.

Blue water consumption (literature)

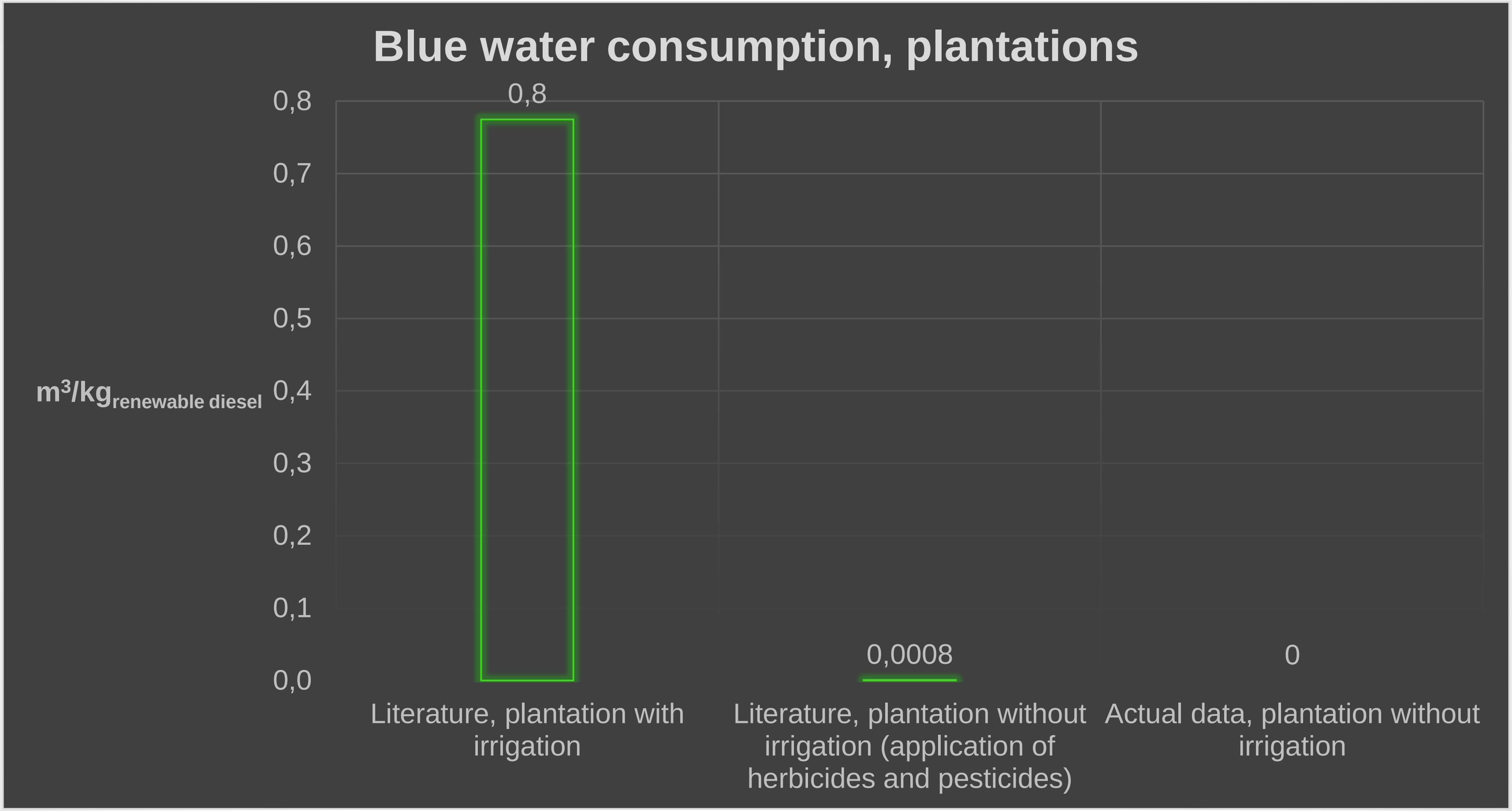


POME release = POME is returned to the same water system that supplies the mill with raw water.
POME land application = POME is applied as irrigation water/fertilizer at the plantation.

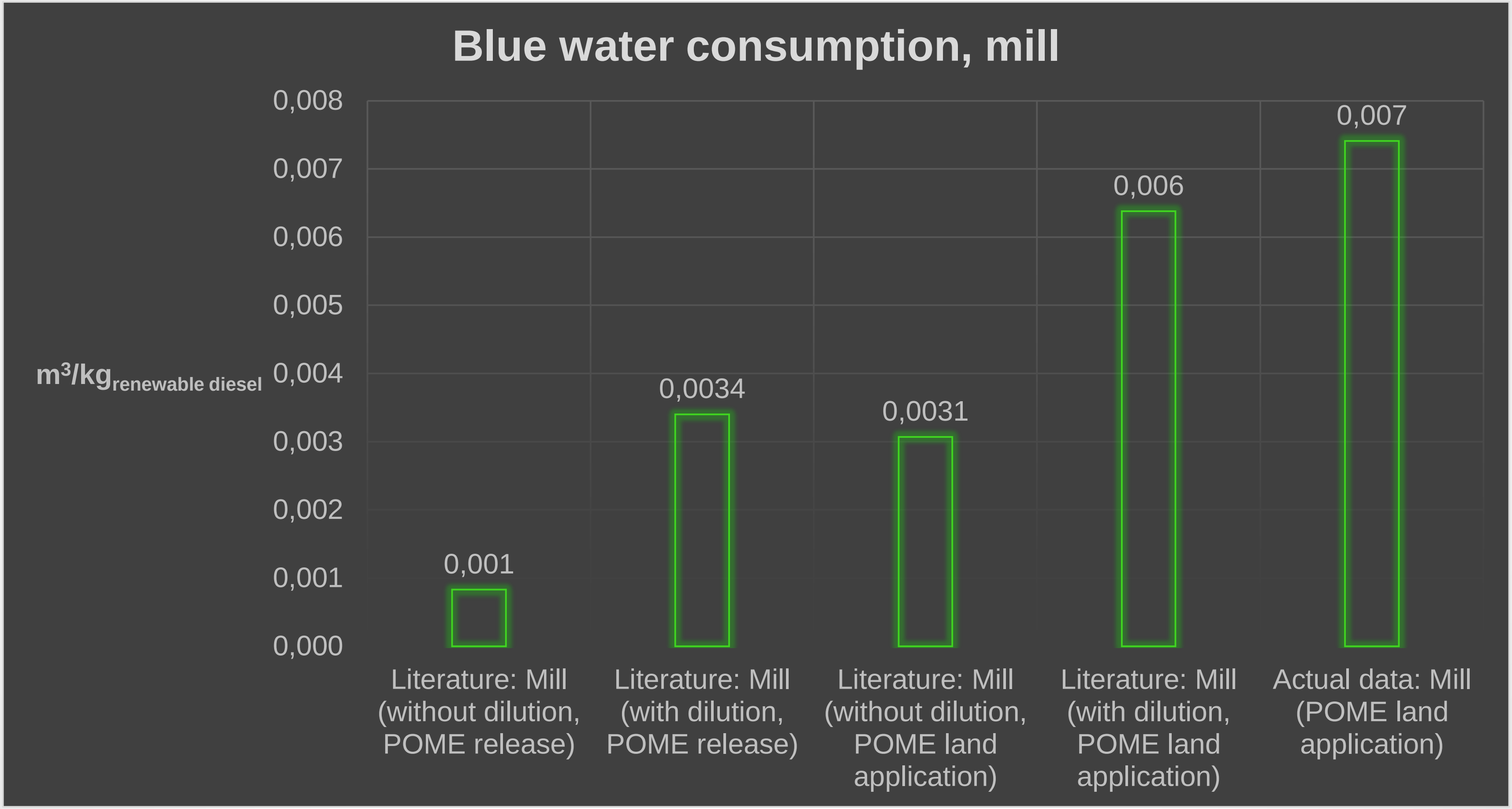
Comparison of blue water consumption: nurseries



Comparison of blue water consumption: plantations



Comparison of blue water consumption: mills



POME release = POME is returned to the same water system that supplies the mill with raw water.
POME land application = POME is applied as irrigation water/fertilizer at the plantation.

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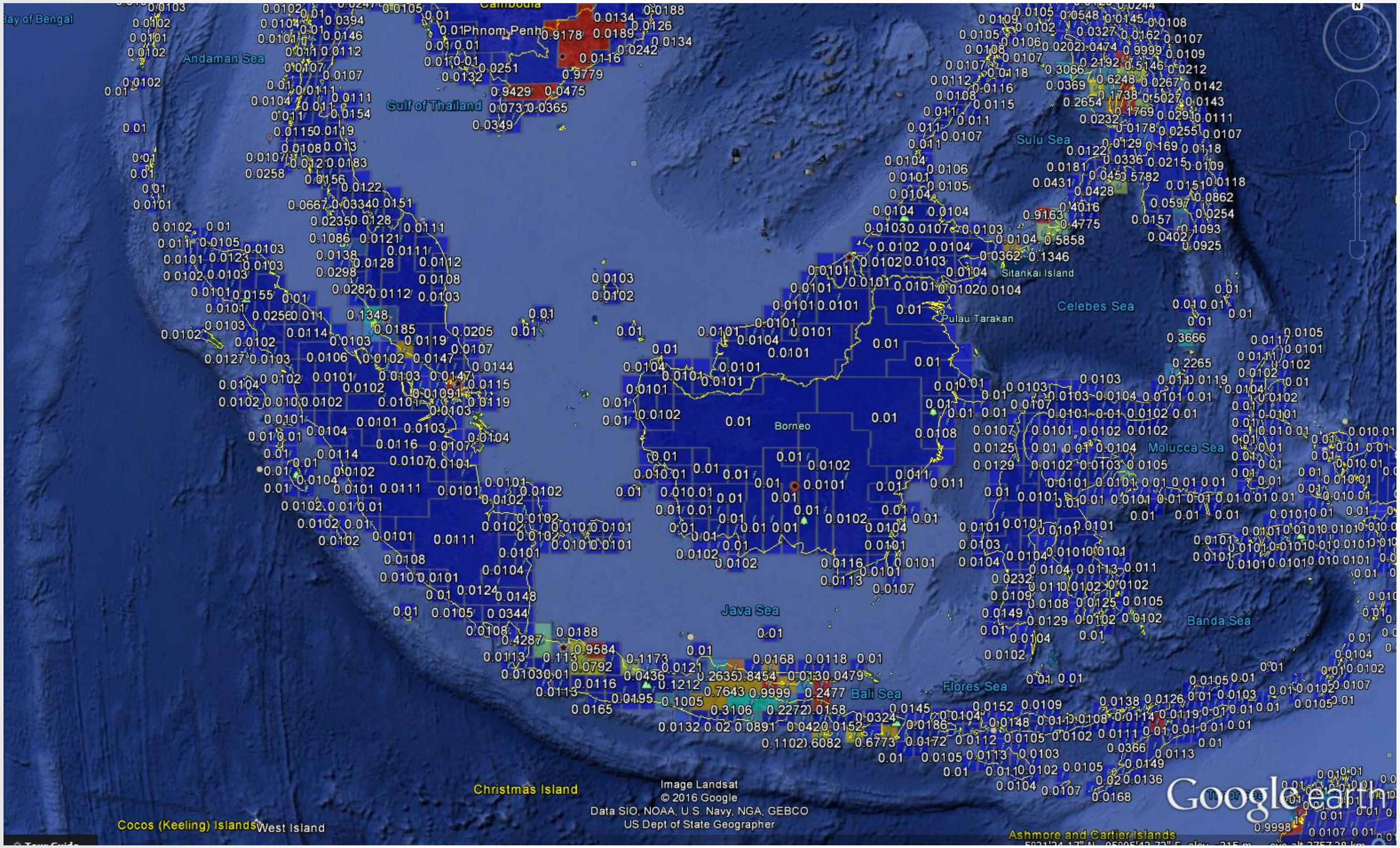
Water scarcity characterisation factors

Water scarcity characterisation factors

Central Kalimantan, Indonesia

WSI = Water stress index = 0,01

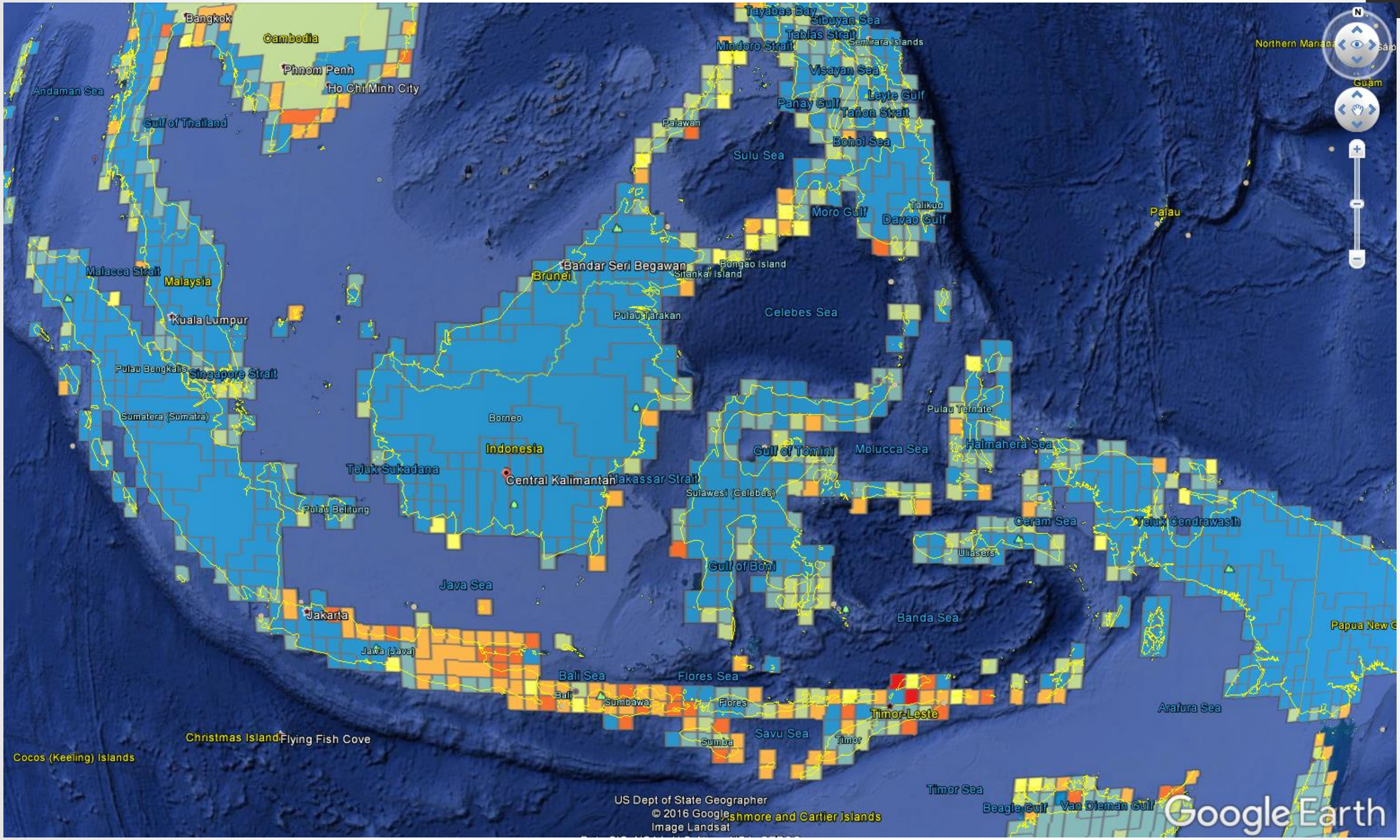
WSI range: 0,01-1 (Pfister et al., 2009)
Average global WSI = 0,44 (Pfister & Bayer, 2014) or 0,602 (Ridoutt & Pfister, 2013; Thylmann, 2014)



(ETH Zürich, 2016)

AWaRe = 0,27 (nurseries, plantations) = 0,26 (mill, bulking)

AWaRe = 1/Unused water remaining range: 0,1-100 (WULCA, 2016)



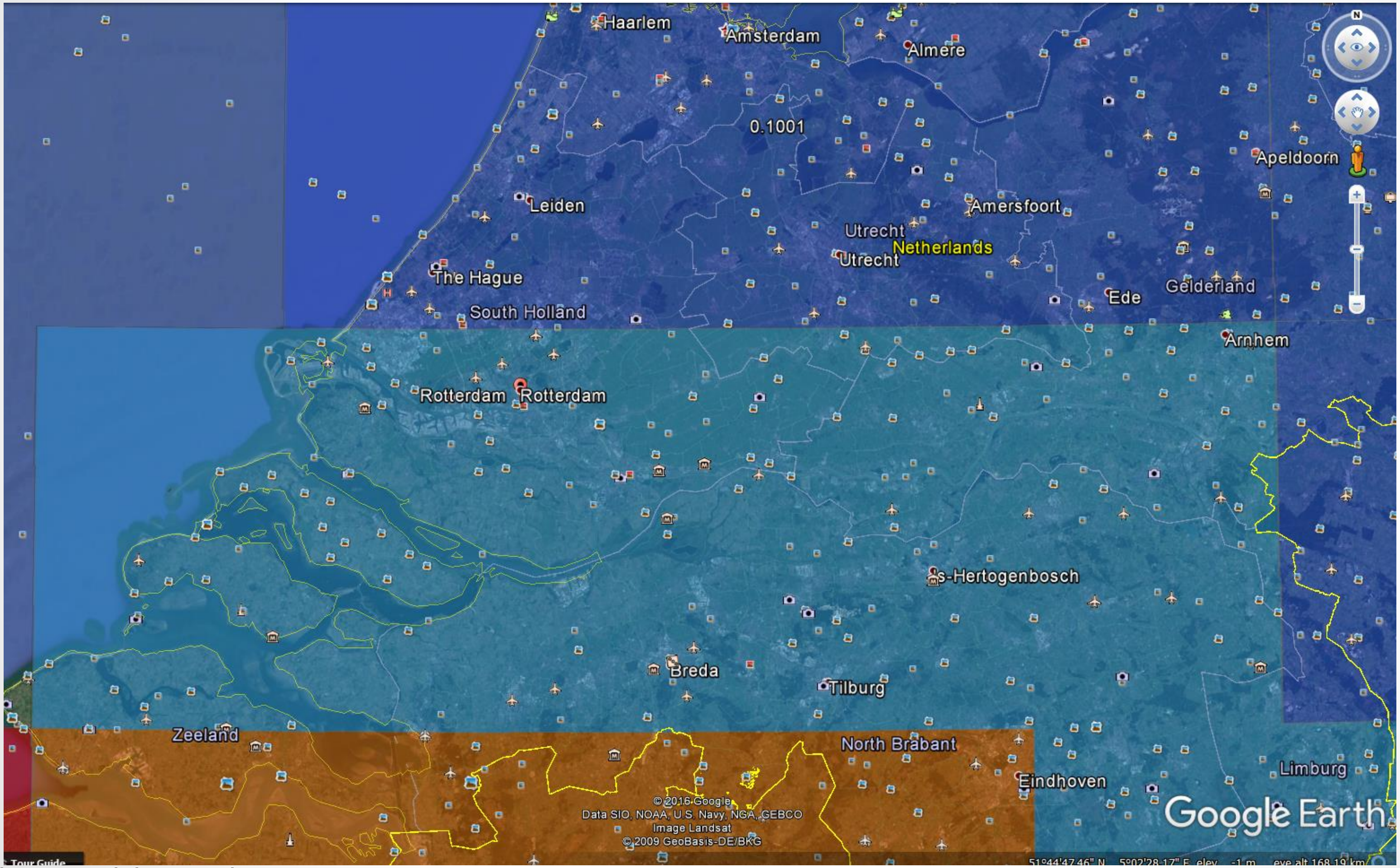
(WULCA, 2016)

Water scarcity characterisation factors

Rotterdam, The Netherlands

WSI = Water stress index = 0,2981

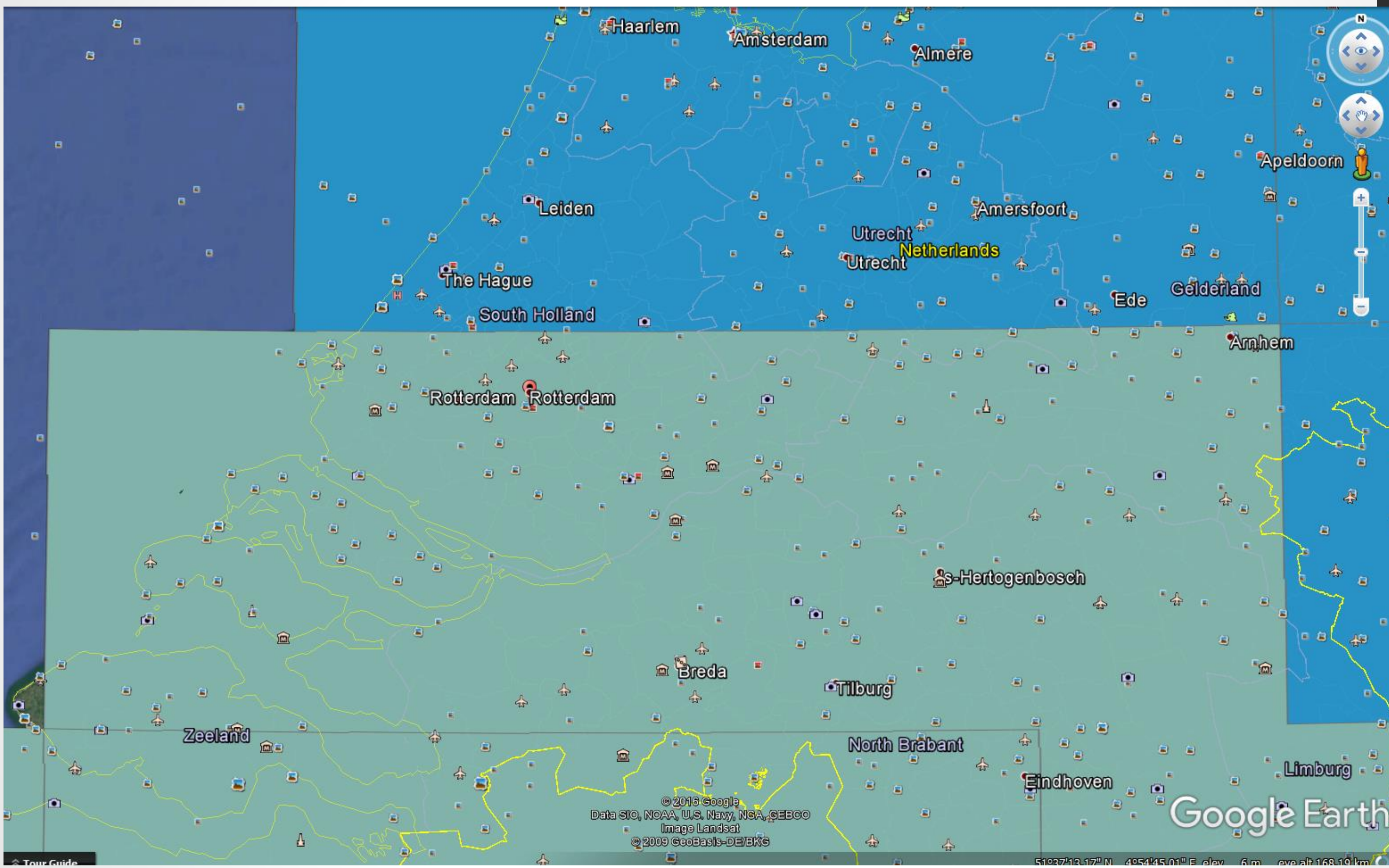
WSI range: 0,01-1 (Pfister et al., 2009)
Average global WSI = 0,44 (Pfister & Bayer, 2014) or 0,602 (Ridoutt & Pfister, 2013; Thylmann, 2014)



(ETH Zürich, 2016)

AWaRe = 1,04

AWaRe = 1/Unused water remaining range: 0,1-100 (WULCA, 2016)



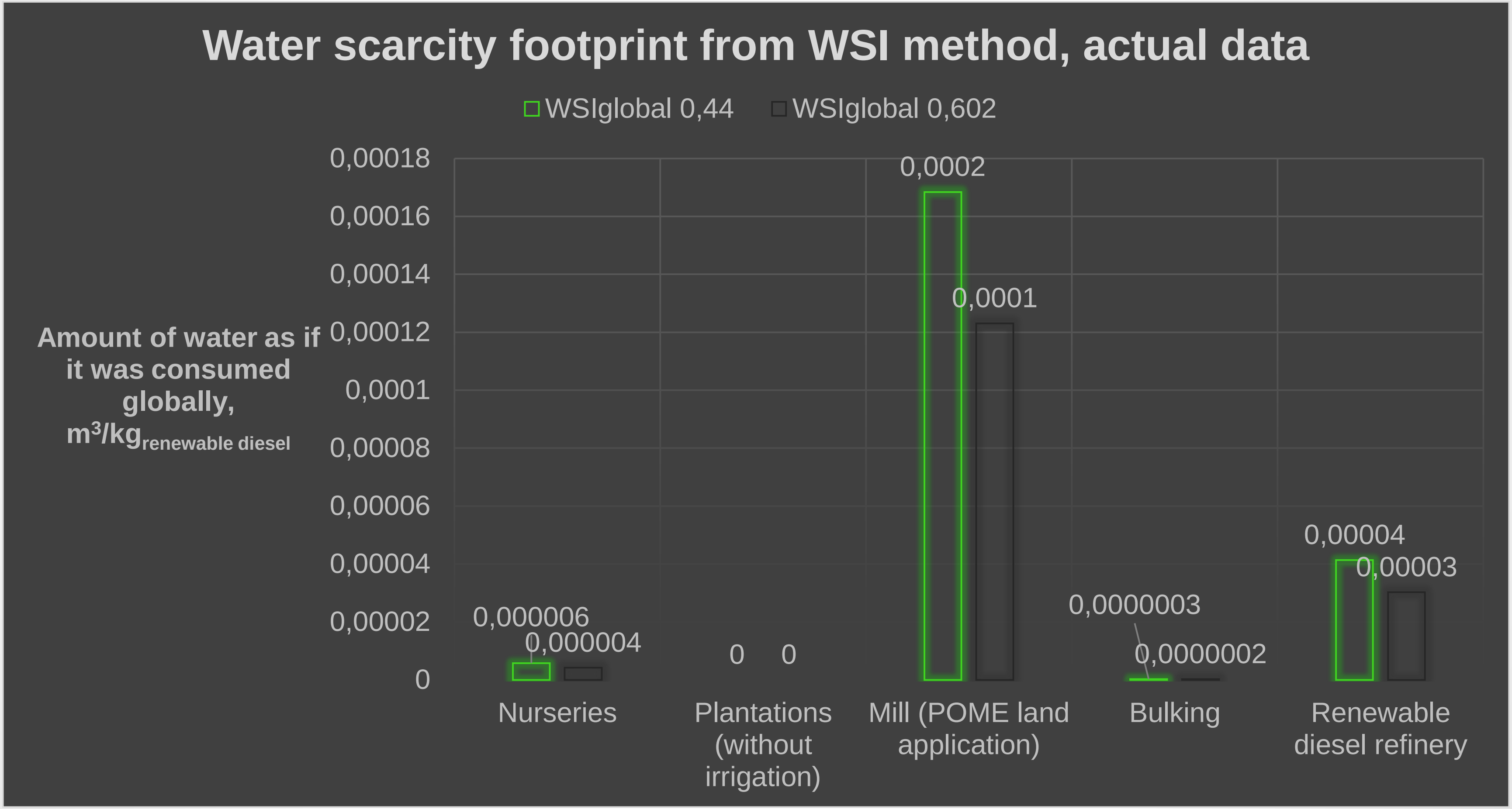
(WULCA, 2016)

Water scarcity footprint results

Water scarcity footprint

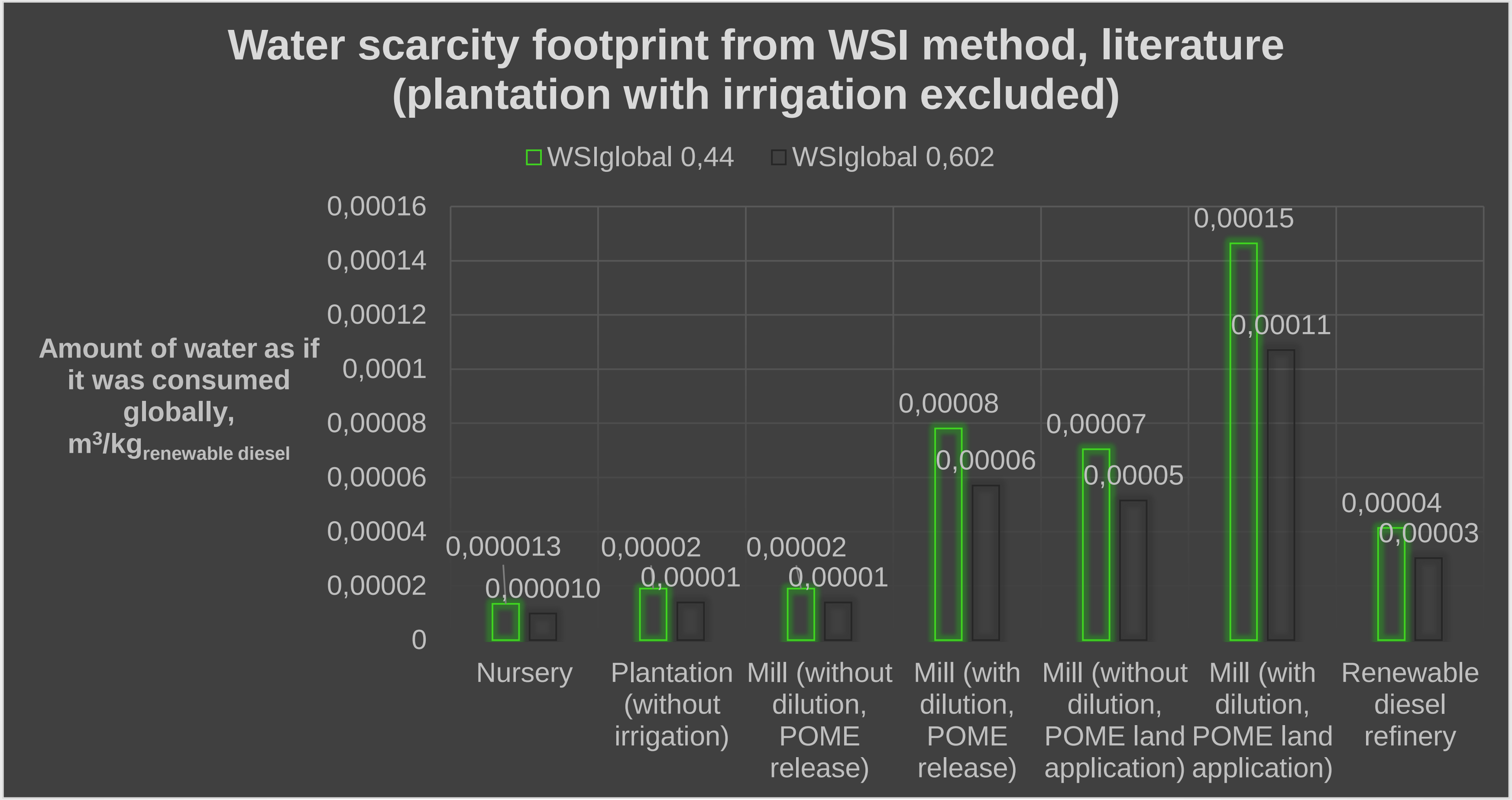
WSI method

Water scarcity footprint, actual data



POME land application = POME is applied as irrigation water/fertilizer at the plantation.

Water scarcity footprint, literature



POME release = POME is returned to the same water system that supplies the mill with raw water.
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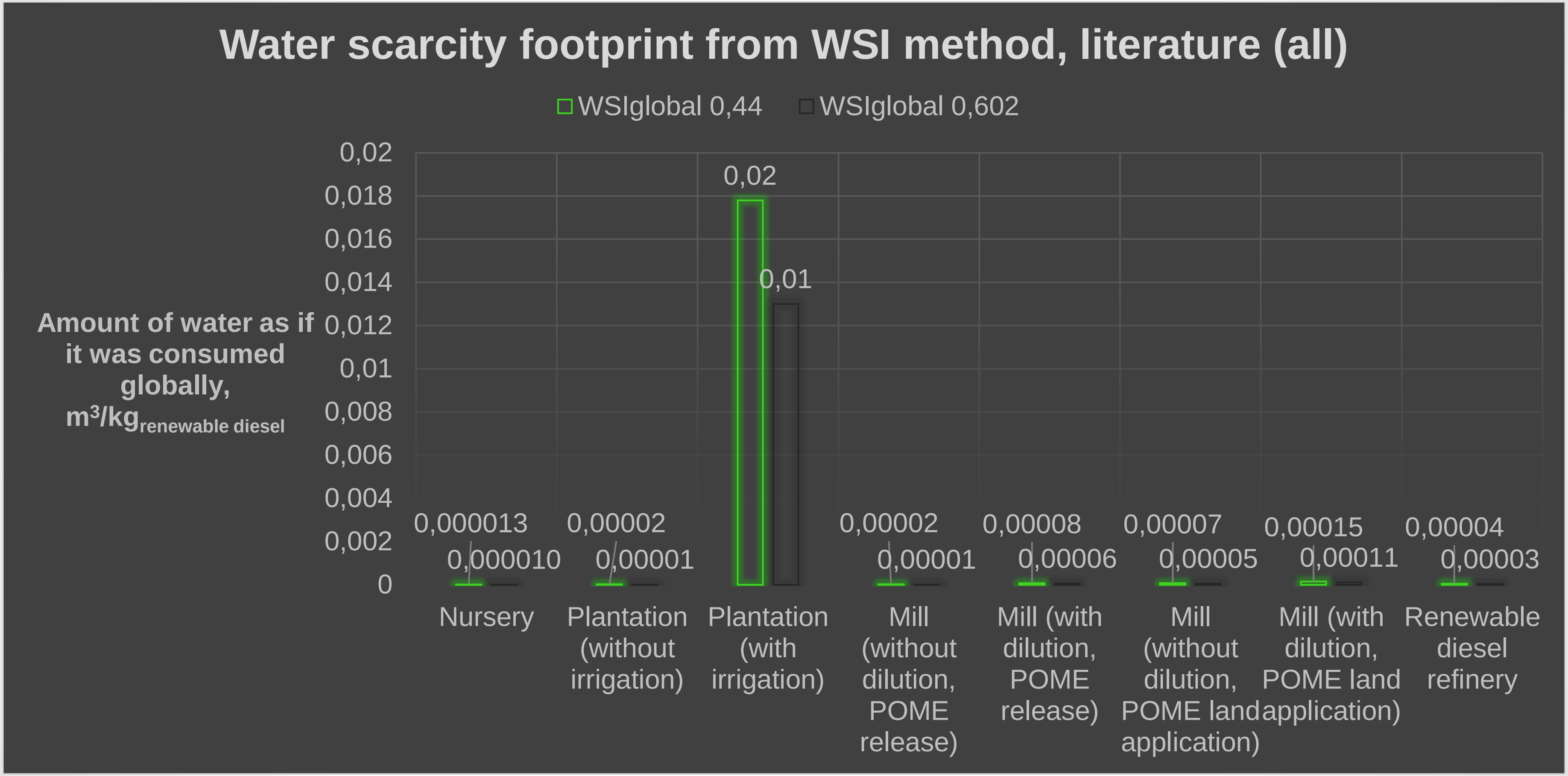
Water scarcity footprint, literature



POME release = POME is returned to the same water system that supplies the mill with raw water.
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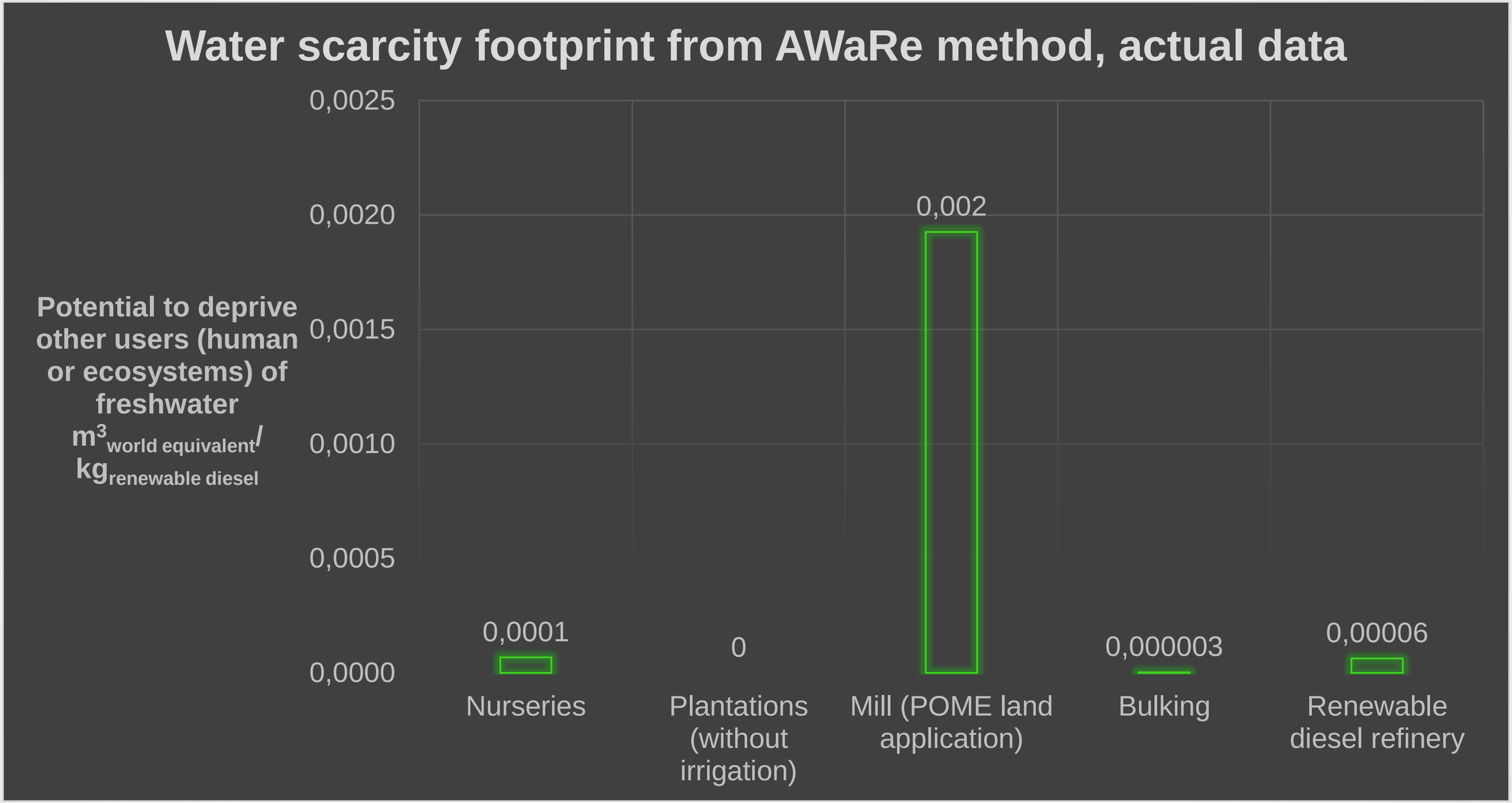
Water scarcity footprint

AWaRe method

Water scarcity footprint, actual data



POME land application = POME is applied as irrigation water/fertilizer at the plantation.

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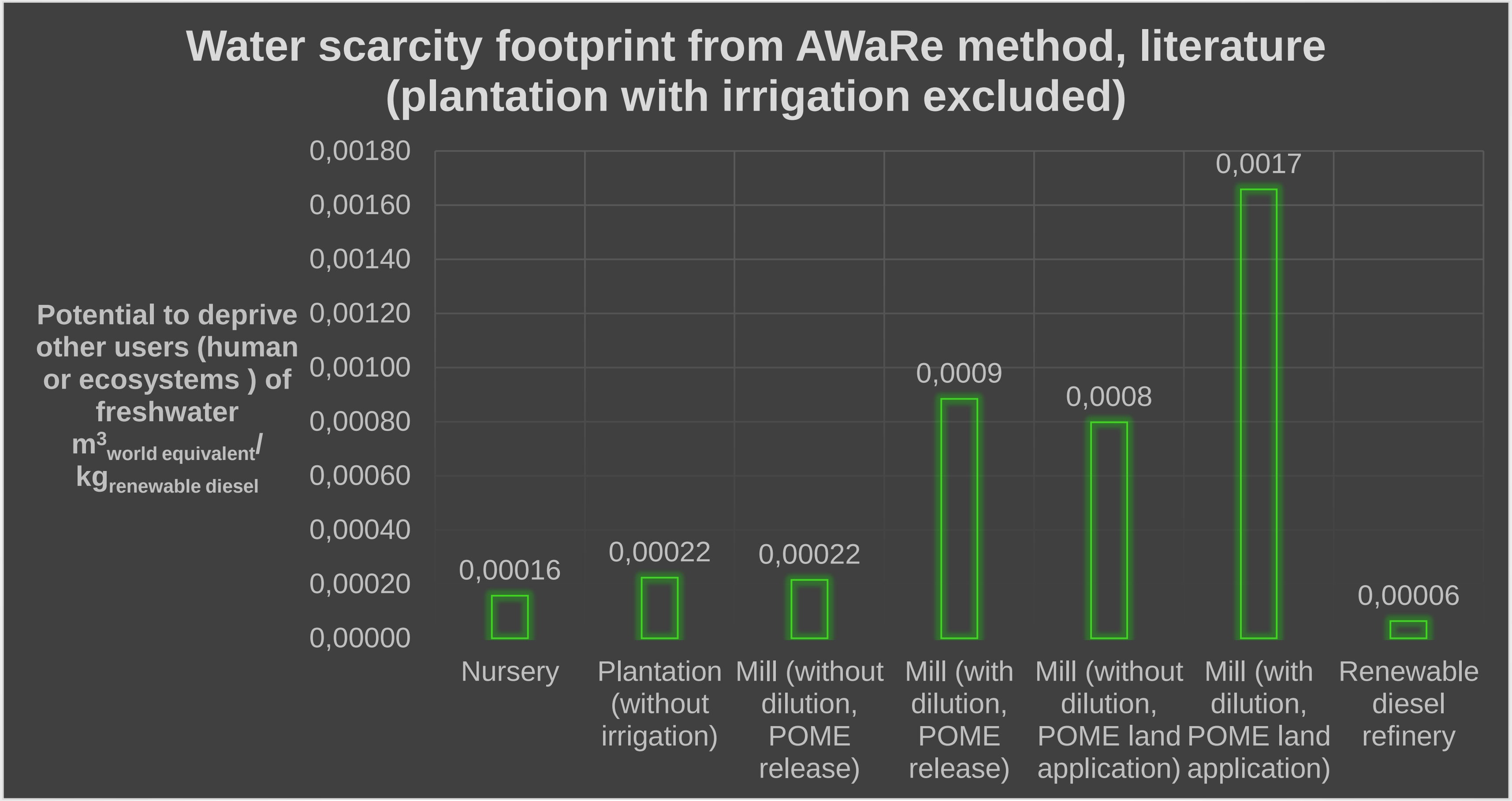
Water scarcity footprint, literature



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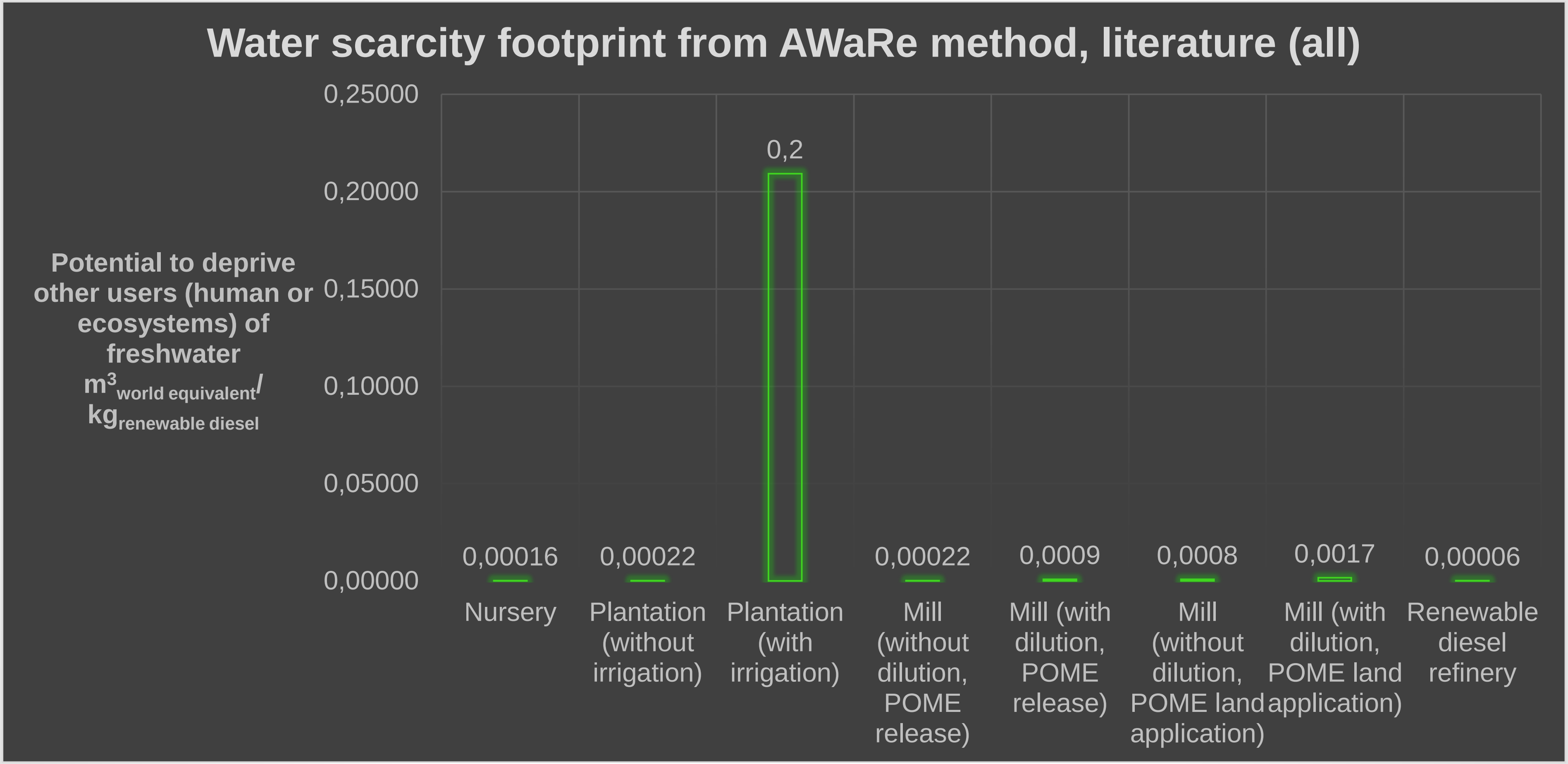
Water scarcity footprint, literature



POME release = POME is returned to the same water system that supplies the mill with raw water.
POME land application = POME is applied as irrigation water/fertilizer at the plantation.

Uncertainties

General uncertainties

- Indirect water consumption could be a further important factor in the water scarcity footprint of renewable diesel, however, it was excluded from this study due to limited time.
- Transportations could be significant in water consumption, however, they were excluded from the study, because they mainly cause indirect water consumption (e.g. through fuel consumption).
- The aggregation of data and use of the WSI and AWaRe factors at annual level instead of monthly level leave out potential seasonal variations in the quantitative availability of water.

Uncertainties of the water scarcity footprint that is based on actual data

- Nurseries
  - Inventory data exists only for one nursery.
  - The water consumption of the other nurseries supplying the other three plantations were assumed to equal the water consumption for irrigation and for the application of herbicides and pesticides at nursery from which data were available.
- Plantations
  - It was assumed that no water is consumed for the application of herbicides and pesticides. It was known that the plantations use water for offices and housing complex, but these were excluded as indirect water consumption so that the water consumption of the plantation without irrigation would correspond the water consumption of the plantation without irrigation based on literature. Furthermore, the offices and housing complex could produce wastewater that is treated and released to the same water system that supplies the raw water for their use, in which case the water consumption could be very low.
- Mill
  - The water consumption of the mill includes the water consumption of the mill and an integrated kernel crushing plant. Thus, the water consumption in the calculations and results is larger than the actual water consumption of the mill.
- General
  - The AWaRe and WSI factors of the nurseries, plantations and bulking were assumed equal to those of the mill. The reason is that the exact locations of those facilities were not used. Only the distance to the mill was known. However, quite minor differences in the AWaRe and WSI factors occur in Central Kalimantan, and thus, the exact location is not a major factor affecting the results.
- Renewable diesel refinery
  - Municipal wastewater discharge was assumed to be into the sea based on the locations of the Rotterdam refinery and the municipal wastewater treatment plants in Rotterdam area. If the water was released back to River Maas, the water footprint would be smaller.

Uncertainties of the water scarcity footprint that is based on literature data

- Calculation of the water scarcity footprint of the nursery, the plantation, the mill and the transportations was based on literature data primarily from Malaysia and partly from Thailand and Indonesia. It was assumed that the data from Malaysia and Thailand correspond with those in Indonesia, however, the possibility of local differences cannot be excluded.
- When literature data included alternative values, either the average value was used or the value that produced the larger water scarcity footprint was selected according to the precautionary principle.
- It was assumed that all irrigation water at the nursery and plantation were consumed for evapotranspiration and the overland flow, infiltration, interflow and baseflow were disregarded. The determination of these other flows would have required more in-depth study of the local conditions (e.g. soil).
- In the literature data, it was assumed that the amount of treated POME equals the amount of raw POME. In the actual data, the amount of treated POME was 95 % higher than the amount of raw POME due to heavy rain in the open lagoon treatment system and possibly difference in the flowmeter calibrations.
- Literature suggests that treated POME from the mill can be used as irrigation water and organic fertilizer at the plantation (Harsono et al. 2012). So POME application at the plantation would decrease the need for irrigation water. In this study, the water scarcity footprint of the plantation was, however, calculated only for a plantation with no irrigation and with full irrigation (no POME replacing irrigation water). If POME was applied in the plantation, the blue water consumption and the water scarcity footprint of the plantation would be somewhere between the results given by these two scenarios. The two scenarios well represent the possible range of the blue water consumption and the water scarcity footprint of the plantation.
- In the literature data-based water scarcity footprint calculations, the effect of POME release to the same water system and use of POME in land application to the plantation was considered.

Uncertainties of the WSI method

- The scientific literature gives two values for the global water stress index. Our results show the results calculated from both values.
- The local Water Stress Index (WSI) is based on the local Withdrawal-to-Availability (WTA) ratio, which is an understandable quantity [m^3/m^3], but as the WSI, i.e. the characterization factor, is calculated from the WTA using the characterization model, the interpretability suffers. The Water Scarcity Footprint is then further retrieved using the WSI.

Discussion and conclusions

Discussion about the methods

- The Withdrawal-to-Availability (WTA) ratio, which is the basis for the Water Scarcity Footprint by Thylmann (2014), disregards use of water for other than human use, whereas the Unused water remaining, which is the basis for the Water Scarcity Footprint calculated using the AWaRe method, takes into account both human and ecosystem water demand. The two Water Scarcity Footprints are not comparable, since the underlying assumptions are different.
- The Water Use in LCA working group (WULCA) recommends using the AWaRe method, which is the most recent development in water scarcity footprinting (e.g. Boulay, 2015).

Discussion about the results from actual data

- The largest blue water consumption is that of the mill (for process and non-process). However, the water consumption includes the consumption of both the mill and the kernel crushing plant, so the actual water consumption would be smaller to what the results suggest.
- The bulking has quite low blue water consumption and water scarcity footprint. If the mill in the system boundaries provided the bulking with boiler water, the blue water consumption of the mill would increase by 0,2 %.
- Central Kalimantan has quite low water stress and plenty of available water remaining (i.e., low values of the water scarcity characterisation factors). For example, the AWaRe factor ranges from 0,1 to 100, and the value in Central Kalimantan (0,26 or 0,27) is clearly at the lower end of the scale. Central Kalimantan seems a justified location of palm oil feedstock production from water scarcity perspective. In general, Indonesia has quite low water scarcity factors, however, there are exceptions such as Central and East Java which locally have AWaRe factors near 70 for agricultural activities.
- The water consumption of the renewable diesel refinery is relatively small. Rotterdam has larger water scarcity characterisation factors than Central Kalimantan. Therefore, the renewable diesel refinery is more significant in relation to the other unit processes as part of the water scarcity footprint than as one of the blue water consuming processes. This example shows that the impact assessment, in this case the calculation of the water scarcity footprint, is important in the comparison of production locations, although the blue water consumption is a useful indicator of e.g. the consequences of water saving measures.

Discussion about the results from literature data

- The literature-based results show that the irrigation of plantation, when applied, is definitely the most significant blue water consuming process.
- The second largest consumer of blue water is the mill, in accordance with the results based on the actual data. Two significant factors, whether the mill practices dilution and whether it releases treated POME into the environment or transports the treated POME to plantation for land application, affect the magnitude of the blue water consumption and water scarcity footprint of the mill. As treated POME could replace both irrigation water and fertilizers at the plantation, its utilisation is a viable option despite the increase of the mill's water scarcity footprint.

Discussion: comparison of the results with previous results in literature

- Caldeira et al. have conducted a case study ”Comparative water footprint profile of vegetable oils for biodiesel production”, in which they calculate the water scarcity footprint using both the AWaRe and WSI method for rapeseed, soybean, palm and waste cooking oil. The palm oil has two alternative cultivation locations: Colombia and Malaysia.
- Both in this study and in the study by Caldeira et al., the mill had the most significant contribution to the water scarcity footprint of the palm oil production stages.
- Similarly to this study, Caldeira et al. calculated quite minor water scarcity footprints for palm oil. In Caldeira et al., only waste cooking oil achieved smaller water scarcity footprints than palm oil. Thus, oil palm seems to be a very sustainable crop from water scarcity point of view.

Conclusions

- The water scarcity footprint is a relatively easy-to-use and understandable tool for the assessment of potential impacts on water scarcity.
- The results of this study are useful in comparing the blue water consumption and the water scarcity footprint of the processes.
- The water scarcity footprint study can be complemented with local water risk assessment to have a more comprehensive view of local water-related sustainability issues.
- The know-how provided by this initial study is a good starting point for further water footprint studies.
- In further studies
  - indirect water consumption and transportations could be included.
  - the water scarcity footprint of different feedstocks in different locations could be compared.
  - a more comprehensive water footprint assessment including water quality aspects could be conducted.

References

The references marked with an asterisk (*) provided the literature data and literature based life cycle depictions

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