SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Solar Energy in Industrial Water & Wastewater Management

SHC Task 62

Final Management Report

92th ExCo Meeting, South Africa

Christoph Brunner
Task Duration: October 2018 – September 2022

Presentation Overview

- Task Overview
- Task Work & Results
- Future Work
- Task Management
- Final Task Evaluation

Task Overview

Task Objective & Scope

Objective

The main objective is to improve the conditions and increase the applications of solar driven separation and water purification technologies in industrial applications to

- push the solar water treatment market,
- solve water problems at locations with abundant solar energy resources and
- reduce the fossil-fuel consumption.

Scope

- Link between industrial separation demand, technologies and exergy heat sources
- New solar thermal collectors' concepts for industrial water treatment
- Technological, economic and political barriers for up-scaling systems and technologies

Task # Subtasks

A. Thermally driven water separation technologies and recovery of valuable resources

- **Subtask leader:** Joachim Koschikowski, Fraunhofer-Institute for Solar Energy Systems ISE
- **Objective:** foster the development and promotion of new energy efficient solar driven separation technologies for industrial waste water and process fluid treatment

B. Solar Water Decontamination and Disinfection Systems

- **Subtask leader:** Isabel Oller, Plataforma Solar de Almería-CIEMAT
- **Objective:** elaboration of emerging technologies integrating solar radiation with increased efficiency and the definition of new solar collectors' concept for reducing manufacture costs though maintaining high efficiency in the collection of UV photons for better performance of chemical oxidation reactions

C. System integration and decision support for end user needs

- **Subtask leader:** Prof. Mikel C. Duke, Victoria University
- **Objective:** to develop a guideline for decision support, designed purposefully for end users/technology adopters, who wish to achieve a certain practical outcome

Participating Countries & Sponsors

Country/Sponsor	National Participation Letter (Y/N)	Number of Experts	Number of Research Institutes	Number of Universities
Austria	Y	2	0	1
Australia	Y	0	4	0
Denmark	N	0	1	1
Germany	Y	2	3	5
Greece	N	2	0	0
Italy	Y	1	3	1
Malaysia	N	0	1	0
Netherlands	N	0	0	3
Portugal	Y	1	1	2
South Africa	N	0	1	1
Spain	Y	4	6	4
Sweden	N	0	1	1
UAE	N	0	2	0
United Kingdom	Y	0	1	0
TOTAL	**7**	**12**	**24**	**18**

Total Person Months: 37,2

Task Collaboration

With other SHC Tasks, IEA TCPs, organizations, etc.

- Collaboration with IEA SHC Task 64 & IEA SHC Task 68
- Exchange on collaboration with the IEA SolarPACES Task VI: Solar Energy and Water Processes and Applications which is led by Diego Alarcón from CIEMAT, Spain
- Collaboration with the Industrial Energy-Related Technologies and Systems Technology collaboration Programme (IETS TCP)
- SPIRE Association
- EACREEE (East African Centre of Excellence for Renewable Energy and Efficiency)
- **With Industry**
- A high number of companies have been active in the Task 62 activities, showing the high interest of industry in the field of solar water management. Industrial involvement especially focused on technology developers related to membrane distillation and water treatment technologies (f.i., TheVap GmbH, Aquastill, Solar Spring).

Task Meetings

Meeting #	Date	Location	Number of Participants & Countries/Sponsors
1	01.-02-10.2018	Graz, Austria	# participants: 11 # countries/sponsors: 7
2	18.-19.03.2019	Almería, Spain	# participants: 33 # countries/sponsors: 7
3	08.-09.10.2019	Freiburg, Germany	# participants: 24 # countries/sponsors:8
4	21—22.04.2020	Online Meeting	# participants: 44 # countries/sponsors:14
5	26. - 27.11.2020	Online Meeting	# participants: 43 # countries/sponsors:10
6	19.04.2021	Online Meeting	# participants: 28 # countries/sponsors:12
7	06..-.07.10.2021	Online Meeting	# participants: 27 # countries/sponsors:9
8	05.04.2022	Graz (Austria) & Online	# participants: 23 # countries/sponsors:8
9	28. – 29.09.2022	Kassel (Germany) & Online	# participants: 9 # countries/sponsors:5

Task Work & Results

Subtask A: Thermally driven water separation technologies and recovery of valuable resources

Main Results & Their Importance

Introduction

Wastewater is a Valuable Resource

- In many regions worldwide water is already a scarce good, even in central Europe decreasing water tables and mismatching extraction and refill ratios lead to water shortage during certain periods of the year with serious impacts for industry, agriculture and nature.

- Pollution of ground and surface water through wastewater disposal and agriculture has serious environmental impact with short- and long-term implication on flora, fauna and human health

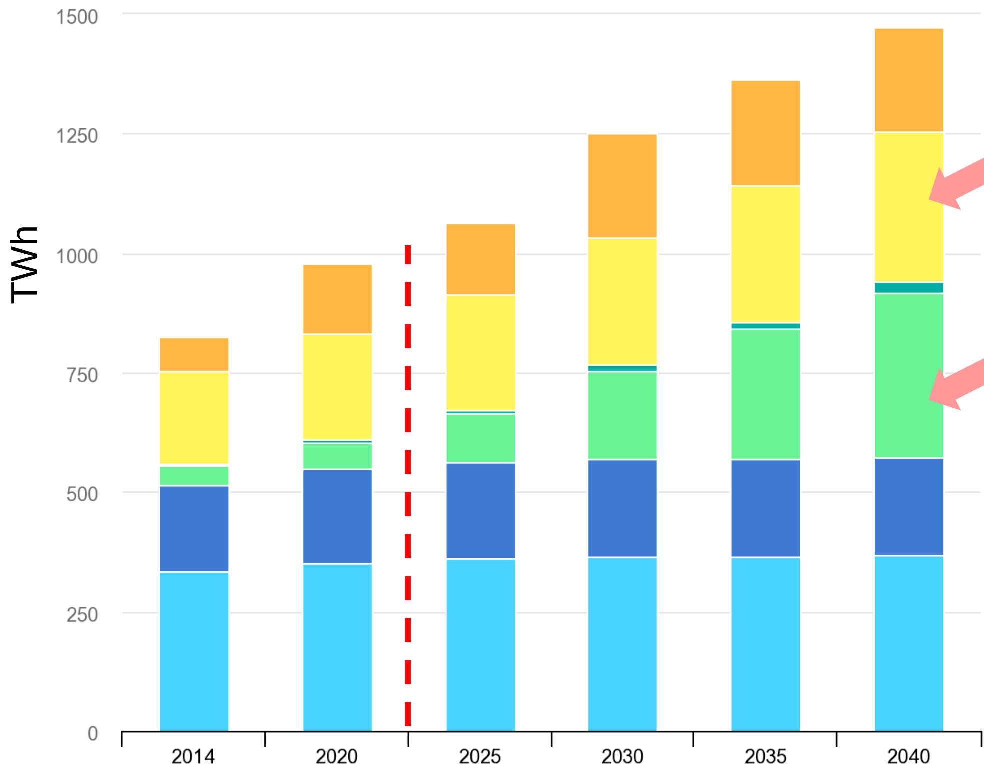
- On the other hand, wastewater and process fluids can be considered as source of valuable materials and must become an essential part of sustainable circular economy approaches

➢ Environmentally friendly technologies for water and material recovery need to be developed

Introduction

Forecast of the electrical energy demand for water treatment

Total increase by 2040: 53% compared to 2020



Wastewater treatment 2040: 22% of total electricity demand and increase by 18%

Desalination 2040: 24% of total energy demand and increase compared to 2020 by 500%

© OECD/IEA

Intensification of water treatment must be sustainable on all aspects !

Notes
*Supply includes ground and surface water treatment

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Objectives of Subtask A

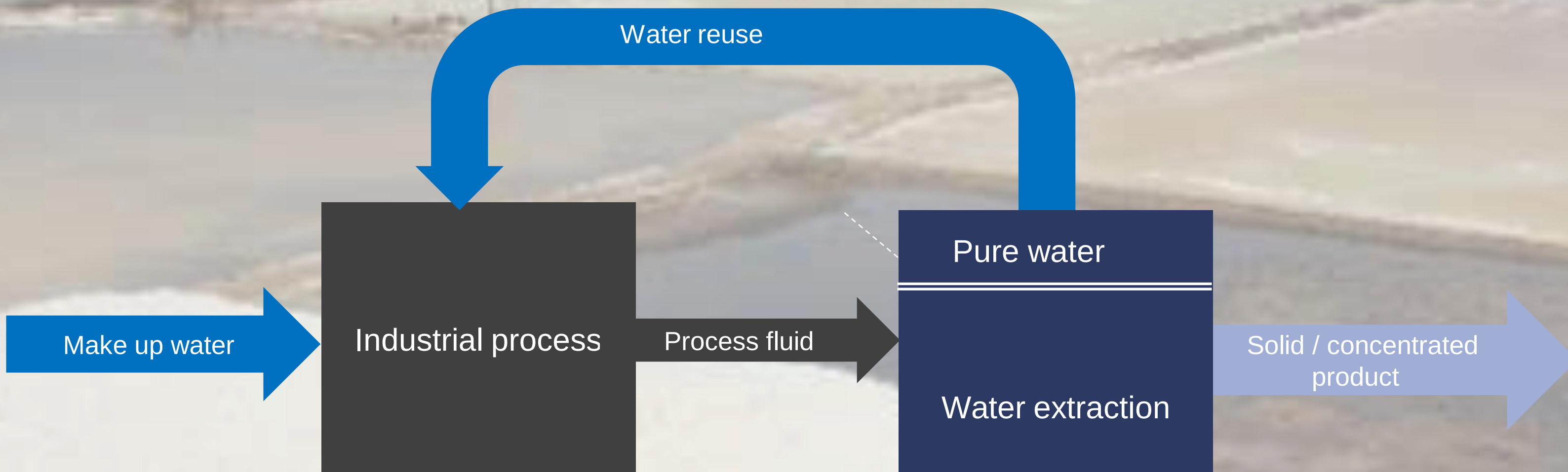
Thermally driven water separation technologies and recovery of valuable resources

The objective of subtask A is to foster the development and promotion of energy efficient solar and waste heat driven separation technologies for industrial wastewater treatment and separation process by:

- Identification of potential applications in industrial water and process stream treatment for the application of thermal separation technologies
- Identification and promotion of advanced separation technologies which are applicable for thermal heat supply (e.g., Membrane Distillation, pervaporation, vacuum evaporation, rectification, etc.)
- Bringing together experts from industry, universities and research centers to identify R&D demand and harmonize R&D topics

Process Technology for Water Extraction

Water extraction from product or waste stream (liquid – liquid and liquid – solid separation)

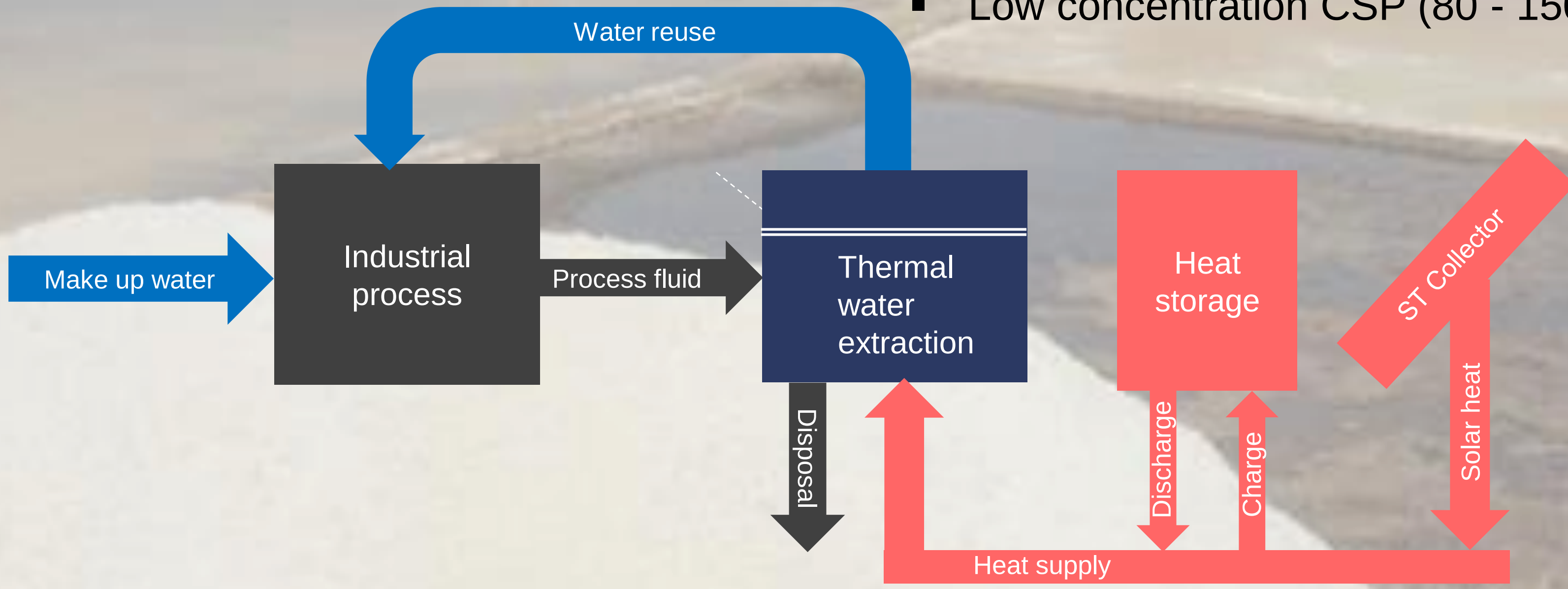


- Single Stage (vacuum) Evaporator
- Multi-Stage Evaporator
- Mechanical vapor Compression
- Humidification – Dehumidification
- Membrane Distillation
- Crystallizer

Process Technology for Water Extraction

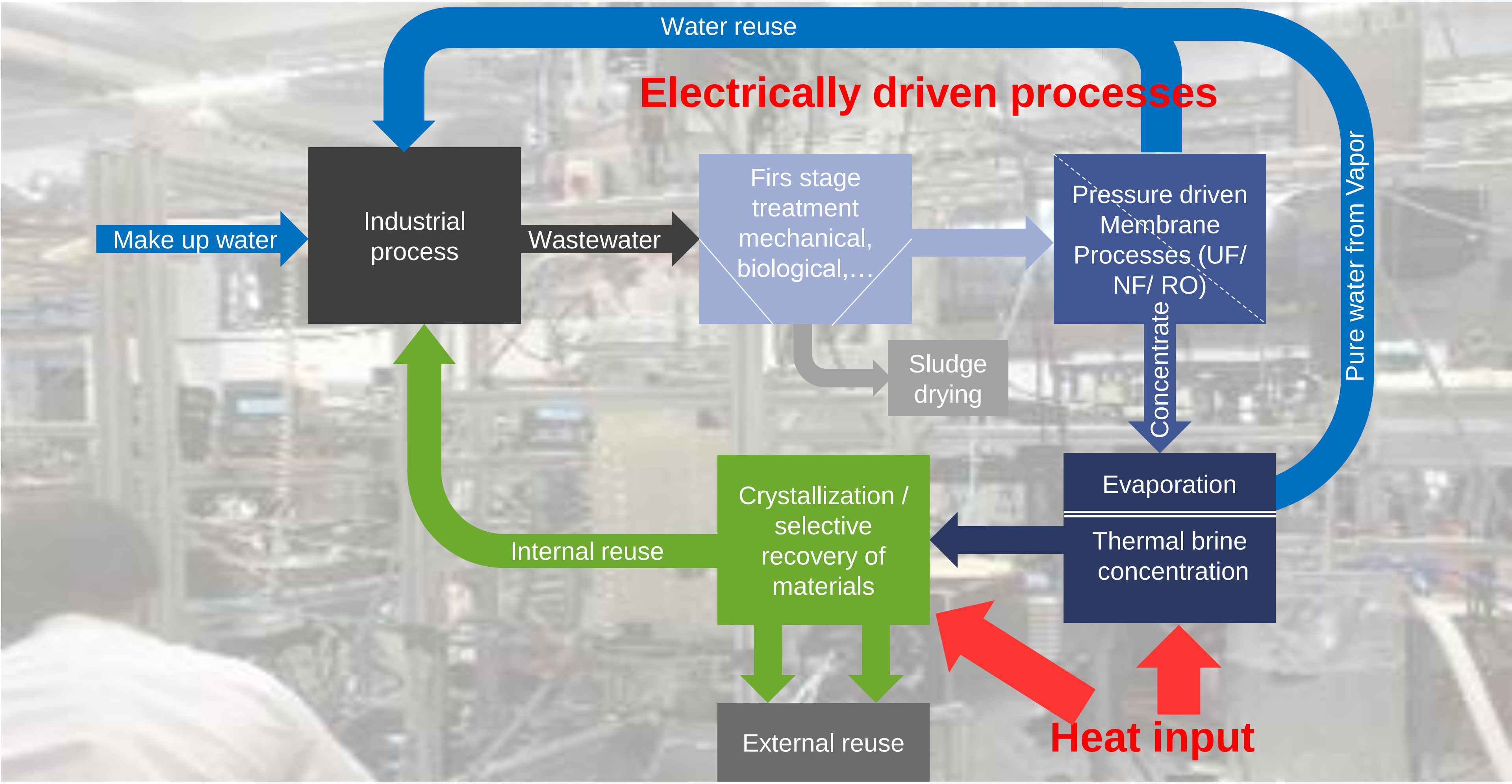
Solar thermal heat supply as exclusive prime mover

- Flat plate collector (60 - 80°C)
- Evacuated tubular collector (80 - 100°C)
- Low concentration CSP (80 - 150°C)



Process Technology for Water Extraction

Deployment of thermal separation technologies in complex treatment chains



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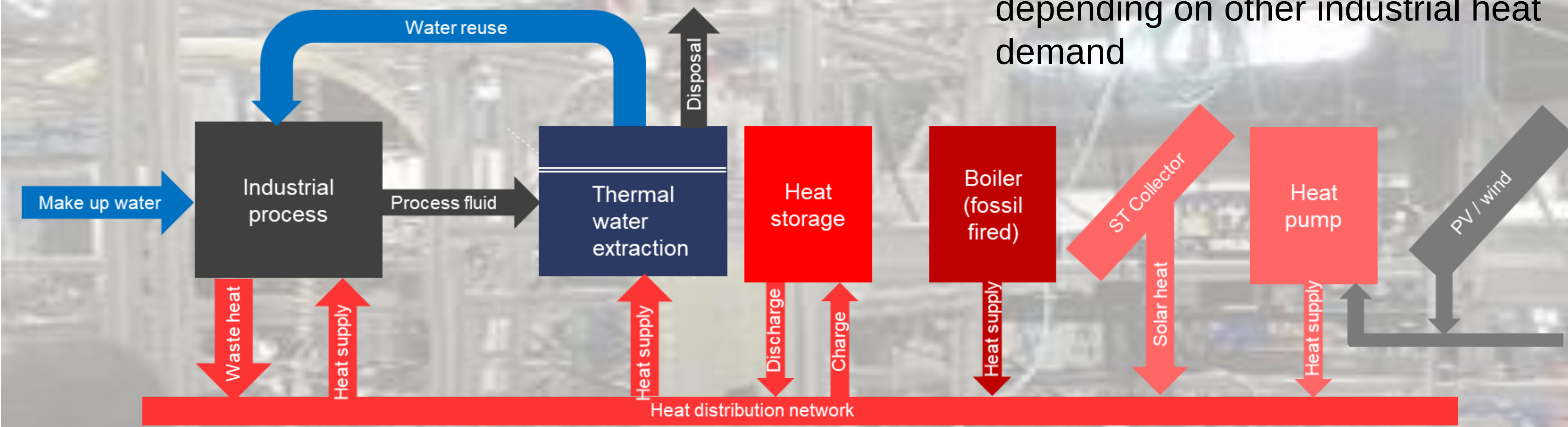
Process Technology for Water Extraction

Solar energy supply as component of a process heat network



Process heat collectors 80 – 250°C depending on other industrial heat demand

Potential Applications and Markets

Application of water treatment technologies in different industries

Industry	Reduction of wastewater – ZLD	Selective recovery and reuse of materials and water from waste streams	Product manufactory and enhancement
Steel, metal and plating industry	▪ Reduction of highly contaminated waste streams (acids, heavy metals,…)	▪ Acids from surface treatment ▪ Metals from surface treatment ▪ Rinsing water	
Semiconductor, printed circuit board and electronic industry		▪ Rinsing water ▪ Metals from circuit board plating ▪ Acids from surface etching ▪ Chemicals from recycling processes	
Chemical, bio and pharmaceutical industry	▪ Complex and expensive to discharge wastewater		▪ Extraction of water ▪ Concentration of products
Textile industry	▪ Cloth Dyeing ▪ Leather tanning ▪ Laundry water	▪ Dyeing and bleaching salts ▪ Laundry Water	
Food and beverage industry	▪ Rinsing and cleaning water ▪ Cheese and whey production ▪ Olive oil production	▪ Water for cleaning and rinsing ▪ Nutrients from process water disposal ▪ Recovery of water and phenol	▪ Concentration of juice ▪ Alcohol extraction ▪ Salt production
Mining industry and salt works	▪ Mine water to reduce environmental impact ▪ Waste streams from leaching	▪ Metal recovery ▪ Acid recovery from leaching	▪ Salt production in from salt lakes and salars ▪ Lithium mining from brines
Oil and Gas industry	▪ Product water reduction - ZLD	▪ Desalination for water reuse	
Pulp and paper industry		▪ Organic compounds ▪ Process water	
Energy production	▪ Cooling water blow down ZLD ▪ Water from mirror cleaning in CSP and PV cleaning	▪ Cooling water ▪ Deionized boiler make up water	

Potential Applications and Markets

Implementation of renewable energy driven water treatment technologies

Opportunities and challenges for emerging treatment technologies

- Complex process chains need high investments and operators are often not well skilled for different technologies
- Wastewater matrices of mixed streams are complex and change frequently
- Complexity of chemical compositions and interactions with materials make lifetime predictions for new applications difficult
- Concerns of plant operators in sensible, high value manufacturing processes as e.g., semi conductor or pharmaceutical industry on insufficient water quality (no failure tolerance)
- In case of ZLD ether huge amounts of "solid waste" need to be disposed or selectively recovered products of sufficient quality need to compete on the market if they cannot be reused on site. Byproducts can be critical!

Potential Applications and Markets

Implementation of renewable energy driven water treatment technologies

Opportunities and challenges for emerging treatment technologies

- Utilization of waste heat is possible if distances are not too far, the decision for solar thermal for wastewater treatment depends on the over all heating concept and is more reasonable for direct water extraction and solids separation. Increasing energy costs support the economic viability.
- In certain applications the recovery of materials and water is already very cost efficient and in several cases reclamation of wastewater is the only option to make fresh water available
- New separation technologies with low CO_2 footprint are indispensable in order to build up the circular economy !
- Today not only economical boundary conditions count but also the security of raw material supply is the driver of commercial and political strategies

Research and Development

R&D demand to foster the implementation of RE driven water treatment technologies

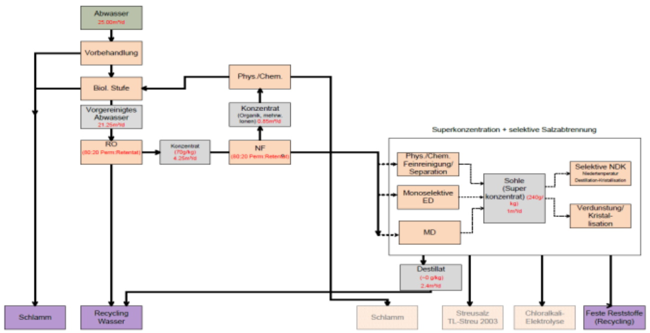
Research topics

- Energy efficiency is the most critical concern and driver of operation costs if not abundant waste heat resources are available. For solar thermal the energy efficiency is directly associated with the investment in the ST plants
- Adaptation to low grade - lowex heat sources is necessary
- Dynamic operation for integration of fluctuating renewable sources
- Low-cost, high corrosion resistant materials with excellent heat resistant and heat conductivity (e.g. modified polymers) must be developed
- Fouling (in particular mineral scaling resistant) materials and coatings must be developed
- Technologies which allow a high selectivity (e.g. fractionated distillation, high purity salt production)

Research and Development

R&D project examples

Connection of pressure driven, electrically and thermally driven membrane processes for process intensification in industrial wastewater treatment



The scope of the BMBF project HighCon:

Reverse **O**smosis - **N**ano **F**iltration – **E**lectro **D**ialysis and **M**embrane **D**istillation for concentration of inorganic compounds in industrial wastewater aiming at:

- **Z**ero **L**iquid **D**ischarge
- Reuse of valuable salts
- Recycling of process water

Project coordination TU Berlin

Research and Development

R&D project examples

Connection of none pressure driven membrane processes as Diffusion Dialysis and Membrane Distillation for acid recovery

The scope of the EU H2020 ReWaCEM project:

Development, construction and operation of 3 demonstration systems in industrial environment for:

- Acid (HCl, H_2SO_4 and HF-HNO_3) recovery from steal plating and pickling processes
- Recovery of metal salts by chemical precipitation
- Recovery of fresh water for process reuse
- Total avoidance of liquid discharge in industrial wastewater treatment

Project coordination Fraunhofer ISE

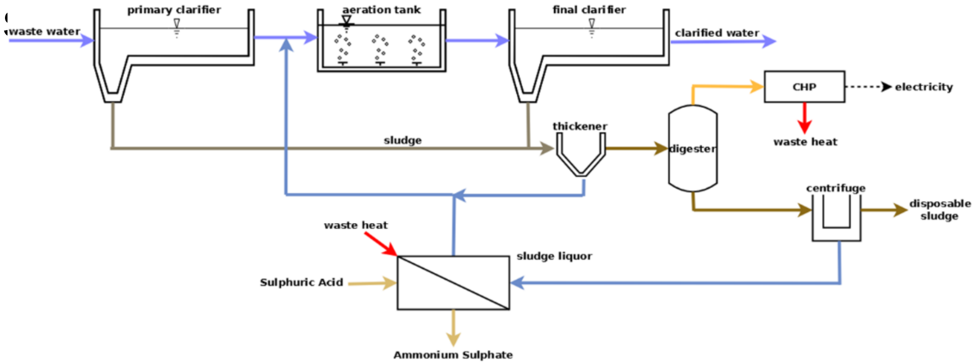
Research and Development

R&D project examples

Recovery of Ammonia from centrate effluent of a wastewater treatment plant and production of ammonia sulphate as fertilizer

The scope of the DBU AmmoniaMD project:

- Removal of ammonia from municipal wastewater by **O**smotic **M**embrane **D**istillation OMD
- Concentration of ammonia sulfate up to 35% utilization as fertilizer
- Transfer to industrial applications
- Development of new OMD membrane contactors



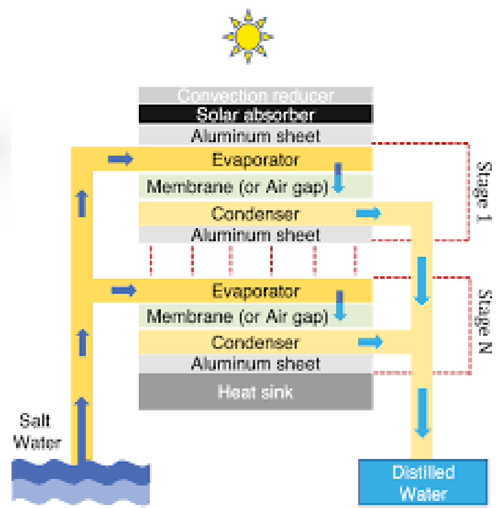
Project coordination SolarSpring GmbH

Research and Development

R&D project examples and transfer to commercial products

Development of distillation systems with integrated solar thermal absorber

Integrated systems for solar thermal water treatment



Solar Dew`s commercial product, integrated membrane-based, solar thermally driven desalination system

Early-stage solar passive distiller developed by Polito Italy

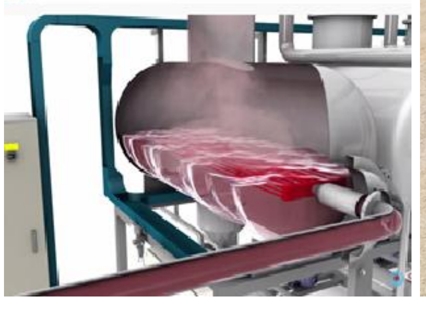
Research and Development

Pilot projects to demonstrate system integration on commercial scale

New solar thermal Fresnel collector concepts for industrial water treatment

Rioglas – Condochem`s Solarvap system

Process heat collectors for heat supply in wastewater treatment of the copper min **Los Frailes near Seville** – Recovery of pure water and reduction of wastewater to ZLD



Subtask B: Solar Water Decontamination and Disinfection Systems

Main Results & Their Importance

Subtask B-CIEMAT-PSA team

Isabel Oller

Solar Treatment of Water Unit CIEMAT-Plataforma Solar de Almería
Almería, Spain
isabel.oller@psa.es

Alba Ruiz Aguirre

Solar Treatment of Water Unit CIEMAT-Plataforma Solar de Almería
Almería, Spain
aruiz@psa.es

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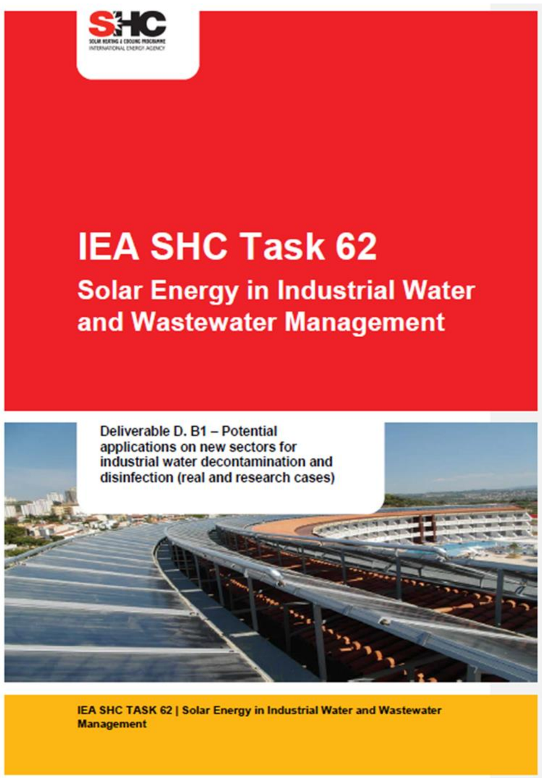
Subtask B – Results of D. B1

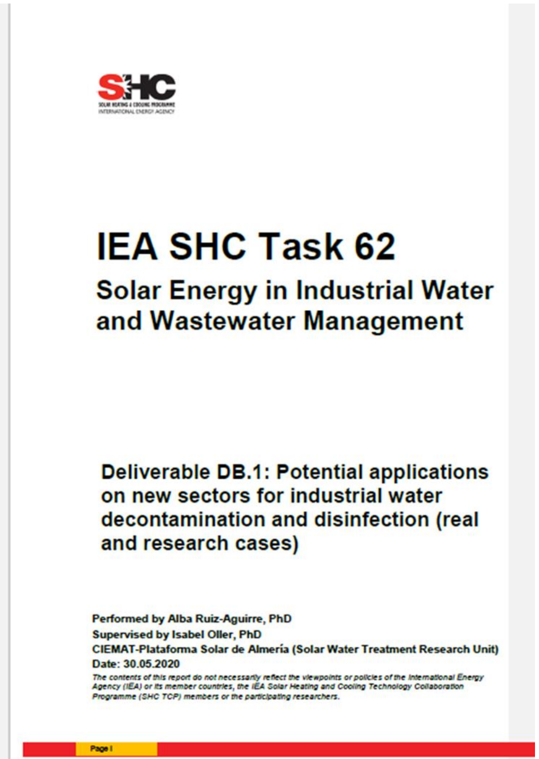
- Potential applications on new sectors for industrial water decontamination and disinfection (real and research cases)


IEA SHC Task 62

Solar Energy in Industrial Water and Wastewater Management

Deliverable D. B1 – Potential applications on new sectors for industrial water decontamination and disinfection (real and research cases)

IEA SHC TASK 62 | Solar Energy in Industrial Water and Wastewater Management


IEA SHC Task 62

Solar Energy in Industrial Water and Wastewater Management

Deliverable DB.1: Potential applications on new sectors for industrial water decontamination and disinfection (real and research cases)

Performed by Alba Ruiz-Aguirre, PhD
Supervised by Isabel Oller, PhD
CIEMAT-Plataforma Solar de Almería (Solar Water Treatment Research Unit)
Date: 30.05.2020

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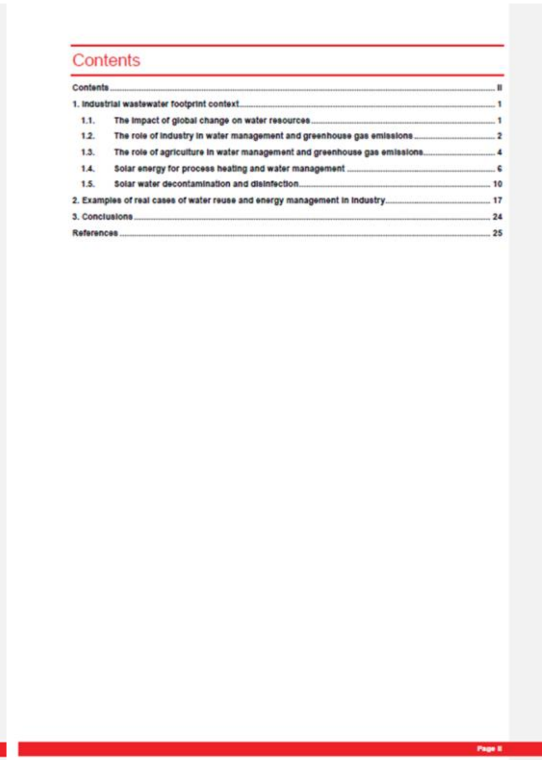
Page I


Contents

Page II

Subtask B – Results of D. B1

Water-Energy in Industrial Sector

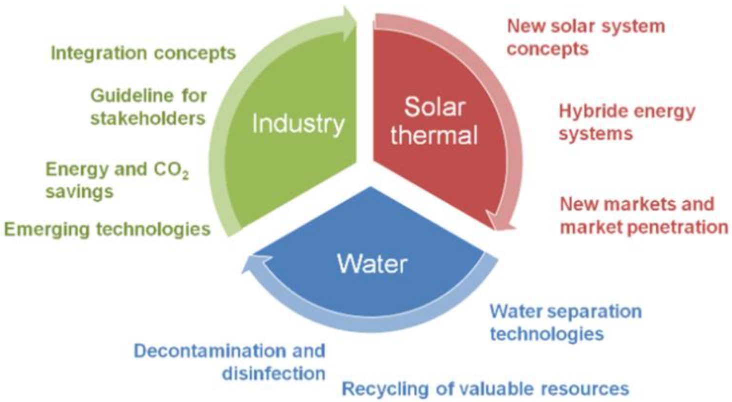


Figure 13. Water use ratio by Coca Cola Company [74].

2. Examples of real cases of water reuse and energy management in industry

- *Coca Cola Company* uses water as ingredient, for cleaning and sanitizing, bottle washer, in cooling towers, boilers, filter backwashing, cleaning of premises, etc. Coca cola facilities have installed monitoring of water use from entrance to the facilities covering each step where water is used, to identify opportunities (Figure 12) [75].

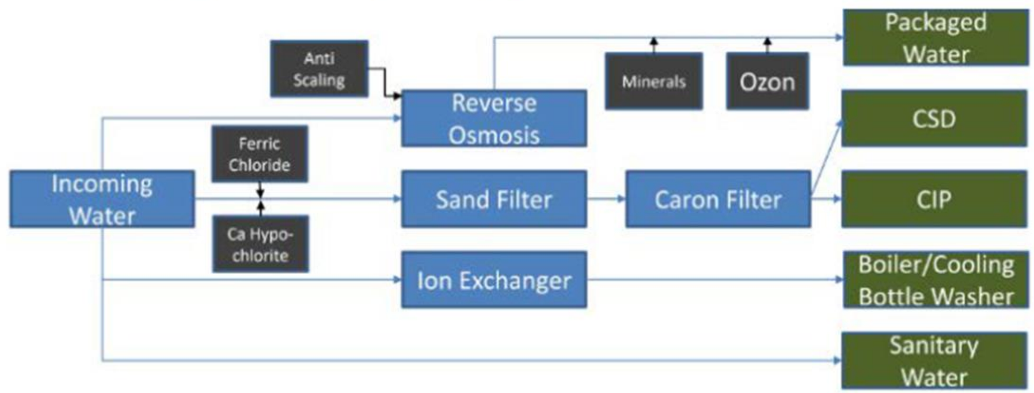
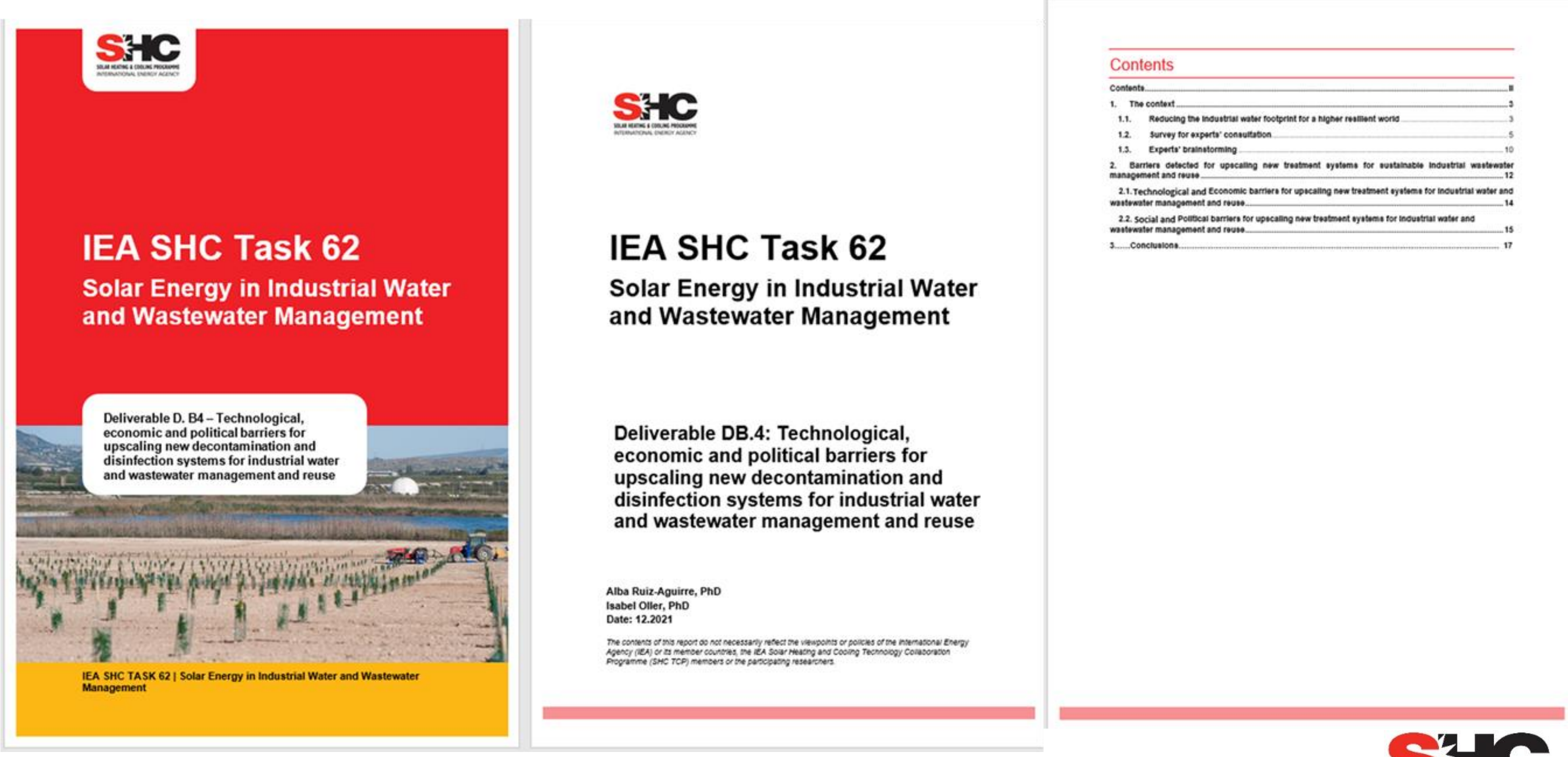


Figure 12. Different uses of water in Coca Cola company [75].

Subtask B – Results of D. B4

- Technological, economic and political barriers for upscaling new decontamination and disinfection systems for industrial water and wastewater management and reuse



IEA SHC Task 62

Solar Energy in Industrial Water and Wastewater Management

Deliverable D. B4 – Technological, economic and political barriers for upscaling new decontamination and disinfection systems for industrial water and wastewater management and reuse

IEA SHC TASK 62 | Solar Energy in Industrial Water and Wastewater Management

IEA SHC Task 62

Solar Energy in Industrial Water and Wastewater Management

Deliverable DB.4: Technological, economic and political barriers for upscaling new decontamination and disinfection systems for industrial water and wastewater management and reuse

Alba Ruiz-Aguirre, PhD
Isabel Oller, PhD
Date: 12.2021

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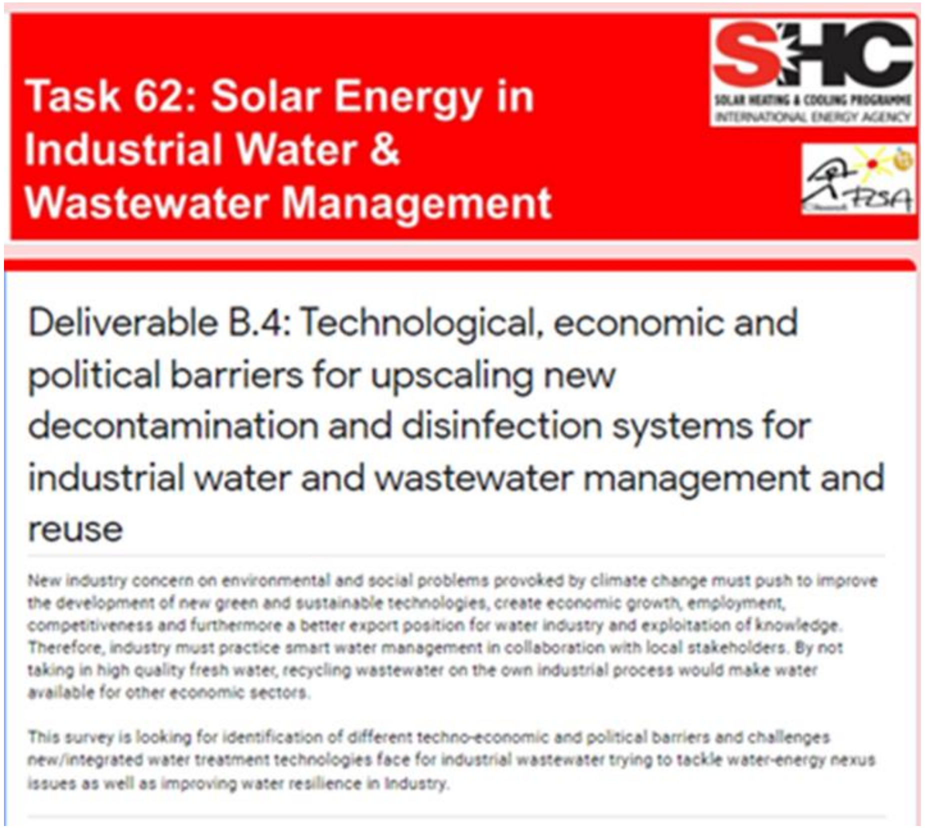
Contents

Subtask B – Results of D. B4



Task 62: Solar Energy in Industrial Water & Wastewater Management

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Deliverable B.4: Technological, economic and political barriers for upscaling new decontamination and disinfection systems for industrial water and wastewater management and reuse

New industry concern on environmental and social problems provoked by climate change must push to improve the development of new green and sustainable technologies, create economic growth, employment, competitiveness and furthermore a better export position for water industry and exploitation of knowledge. Therefore, industry must practice smart water management in collaboration with local stakeholders. By not taking in high quality fresh water, recycling wastewater on the own industrial process would make water available for other economic sectors.

This survey is looking for identification of different techno-economic and political barriers and challenges new/integrated water treatment technologies face for industrial wastewater trying to tackle water-energy nexus issues as well as improving water resilience in Industry.

Technological Barrier:

Economic Barrier:

Political Barrier:

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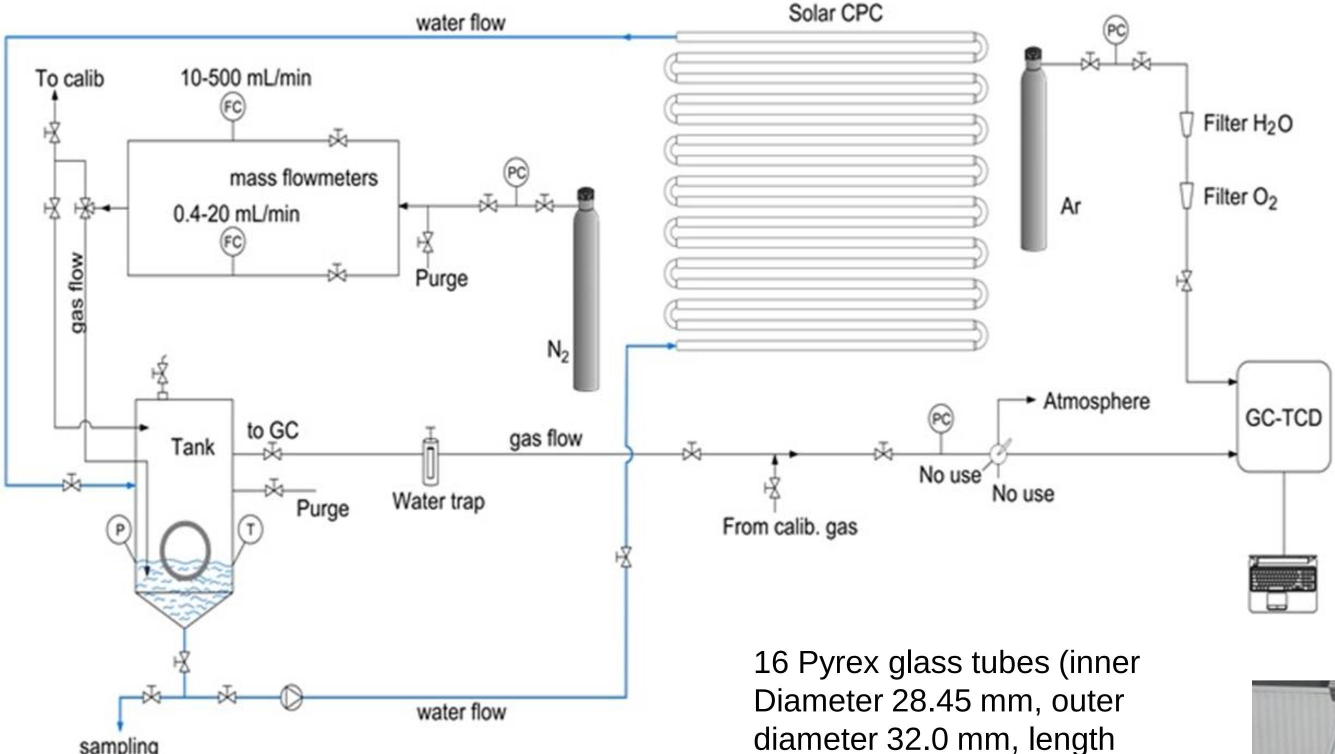
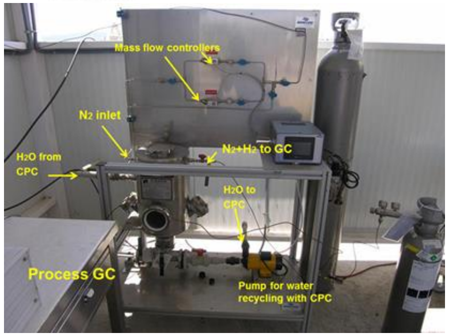
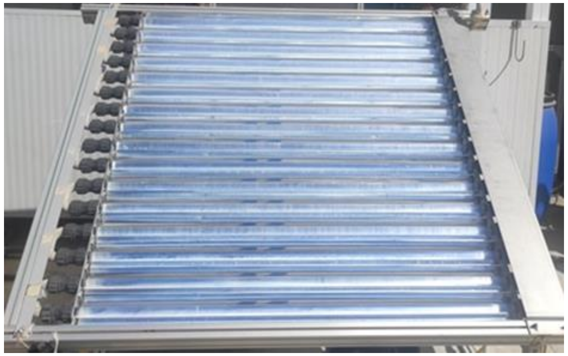
Subtask B – Results of D. B2



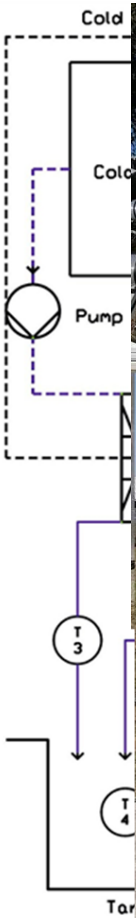


"New solar collectors' concepts for hydrogen production and industrial water decontamination & disinfection "

16 Pyrex glass tubes (inner Diameter 28.45 mm, outer diameter 32.0 mm, length 1530.0 mm) mounted on a fixed platform tilted 37 (local latitude).
- Total area irradiated of 2.1 m^2
- Total irradiated volume of 14.24 L.
- Total slurry volume of 25 L



Subtask B – Results of D. B2



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Subtask B – Results of D. B2

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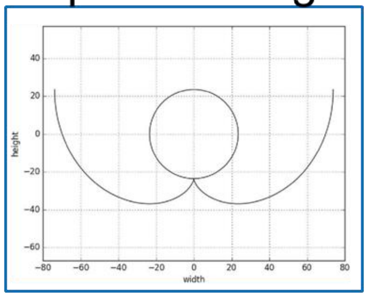
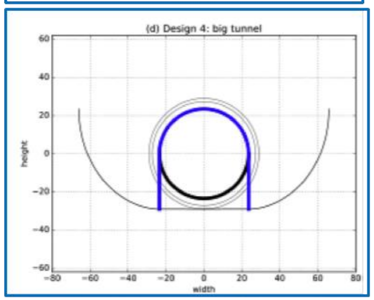
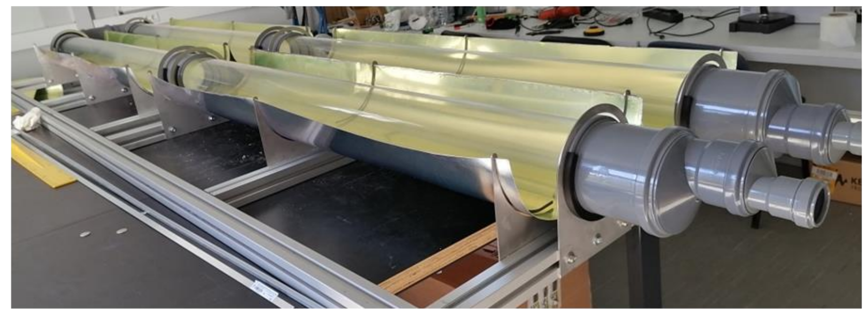
One-Sun Compound Parabolic Collectors (CPC)

simplified design for low cost production (“big tunnel”), Osório et al. (2019)





Solar collector was obtained by molding the CPC-type profile over the receiver length



Electro-brightened pre-coated mirror finished aluminium (SWR686)

- ≥84% Total solar reflectance
- ≥87% Total solar reflectance “visible range”
- <3% Diffuse reflectance
- ≥80% Specular reflectance.

Dimensions:

- Aa = 305.64 mm^2
- Perimeter = 453.23 mm
- Aperture area = 1.83 m^2

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Subtask B – Results of D. B2

Tubular Receivers

The **horizontal receivers** are connected in series

- 4 tubes
- borosilicate glass 3.3 DURAN®
- 125 mm outer diameter,
- 5 mm wall thickness and
- 1.5 m length
- with tubes and valves made of HDPE

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Subtask B – Results of D. B2

SOLARDEW
CLEAN WATER SOLUTIONS

PROTOTYPE EVALUATION

SolarDew's pre-production prototypes were tested:

- In the lab at Water Test Network
- In the field at Plataforma Solar De Almeria
- In the field with partners in Australia

The prototypes

- Were manufactured using the same production processes we aim to use at scale
- Uncoated membranes (coated not available due to COVID)
- Smaller active area of 0.06 m2 vs. 0.45 m2 for production version
- Equipped with dataloggers to monitor climate, temperatures and production.
- Pre-tested in SOlarDew's lab and in the field NL

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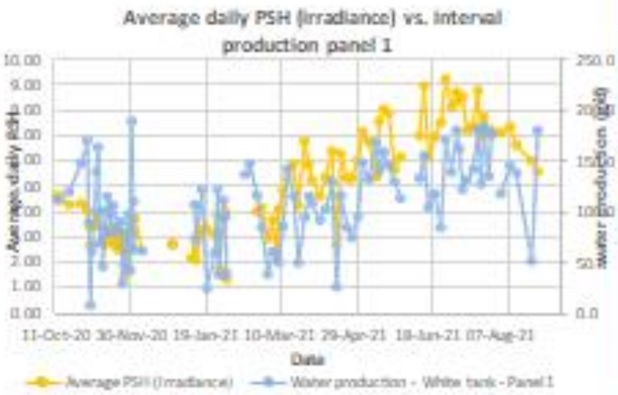
Subtask B – Results of D. B2



SOLARDEW
CLEAN WATER SOLUTIONS

PLATAFORMA SOLAR ALMERIA

Objective – Evaluate long term performance in representative conditions.

- 2 single layer prototypes
- Oct 2020 to Oct 2021
- Isabel Oller Alberola, Inmaculada Polo Lopez and Alba Ruiz Aguirre

Results

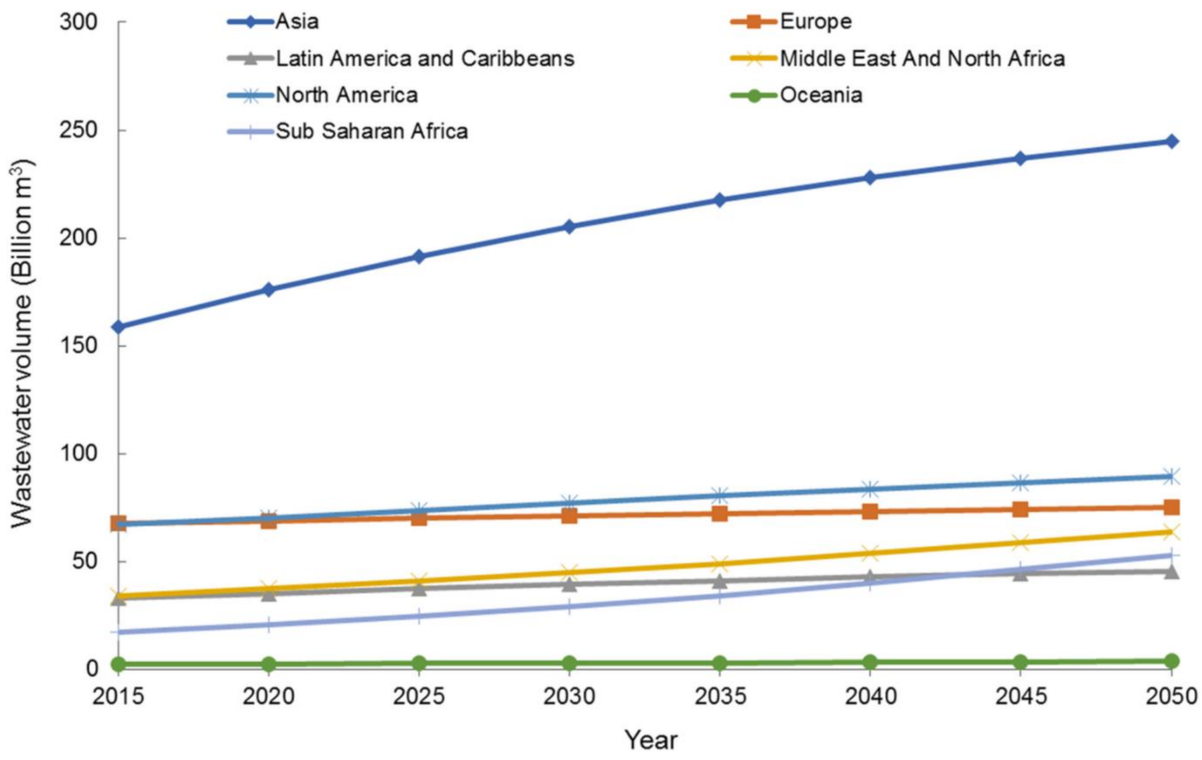
- Produced distilled water (<10 uS/cm) from seawater (46,000 uS/cm) in a single step
- Recontamination prevention is essebtuak for long term storage
- Avg. 2.2 l/m2/day @ 2056 kWh/m2/year (70% of expected for a single layer)
- Max. 3.9/m2/day @2973 kWh/m2/year
- Good temperature resistance (min. -2.5 C and max. 90.4 C)

Subtask B – Results of D. B5

“Report on legal thresholds for accomplishing water quality required depending on the final application”

Water Reclamation, a global need

It is estimated an annual world production of **urban wastewater of 380 km³**, that is 15% of water withdrawal for agriculture (42 millions ha).
World urban wastewater production is estimated to increase **24% in 2030 and 51% in 2050**.



Nutrients in urban wastewaters:
16.6 Tg (Tg = million of metric tons) of nitrogen; 3 Tg for phosphorous and 6.3 Tg for potassium.
Total recovery of nutrients from urban wastewaters would compensate the 13.4% of the world demand for agriculture.

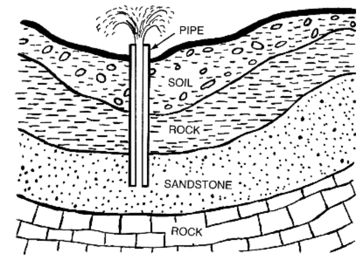
Subtask B – Results of D. B5

Benefits

- It can improve the status of the environment both quantitatively, <u>alleviating pressure by substituting abstraction</u>, and qualitatively, <u>relieving pressure of discharge from UWWTP to sensitive</u> areas.

✓ Environmental
✓ Social
✓ Economic

- Appropriate consideration for <u>nutrients</u> in treated wastewater could also reduce the use of <u>additional fertilizers</u> resulting in savings for the environment, farmers and wastewater treatment.

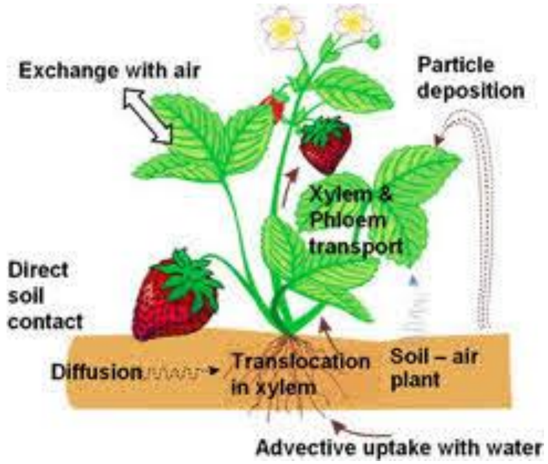


- It is considered a <u>reliable water supply</u>, quite <u>independent</u> from seasonal drought and weather variability and able to cover peaks of water demand.

- <u>Lower investment costs and energy</u> compared to alternative sources such as desalination or water transfer, also contributing to reduce greenhouse gas emissions.

Subtask B – Results of D. B5

OMCs translocation to plants and detection



Pharmaceutical	Plant	Spiked concentration	Study duration (days)	Mean concentration detected in plant (μg/g)		
				Roots	Stem	Leaves
Diclofenac	*Typha latifolia*	1 mg/L	1	0.2	Not reported	0.013
Fluoxetine hydrochloride	*Brassicaceae*	280 ng/mL	12 weeks	Not detected	0.49	0.26
Carbamazepine	Cucumber	4.14 μg/L	3 months	4.5[a]	1.9[a]	39.1[a]
	Scirpus validus	0.5–2.0 mg/L	21	3.3–19.0	Not reported	0.3–0.7
Naproxen	*Scirpus validus*	0.5–2.0 mg/L	21	0.2–2.4	Not reported	0.3–0.7
Diclofenac	*Medicago sativa* L.	10 μg/L	50	162.8[a]	Not reported	Not detected
Sulfamethoxazole	*Medicago sativa* L.	10 μg/L	50	52.5[a]	Not reported	3.5[a]
Trimethoprim	*Medicago sativa* L.	10 μg/L	50	311.9[a]	Not reported	23.5[a]
17α-Ethinylestradiol	*Medicago sativa* L.	10 μg/L	50	28.9[a]	Not reported	28.3[a]

[a] Concentrations are given in μg/kg.

L.M. Madikizela et al. / Science of the Total Environment 636 (2018) 477–486

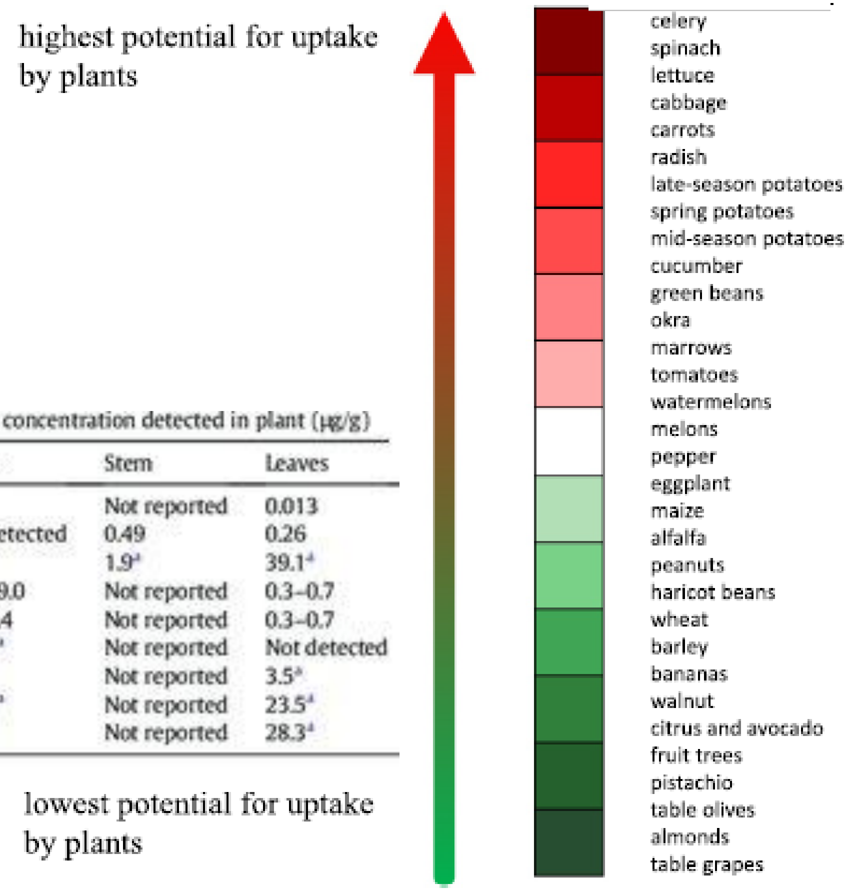
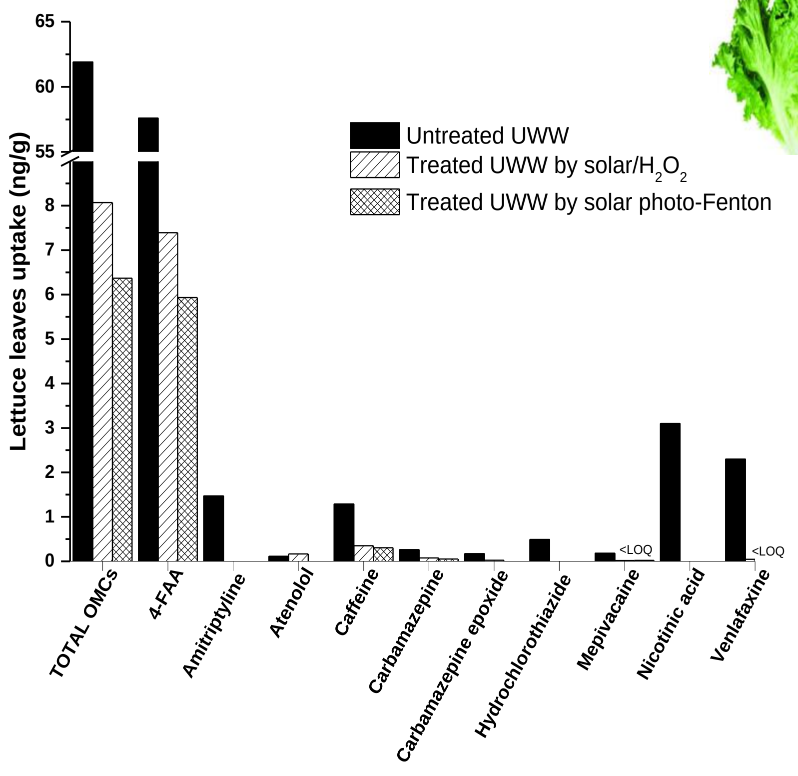


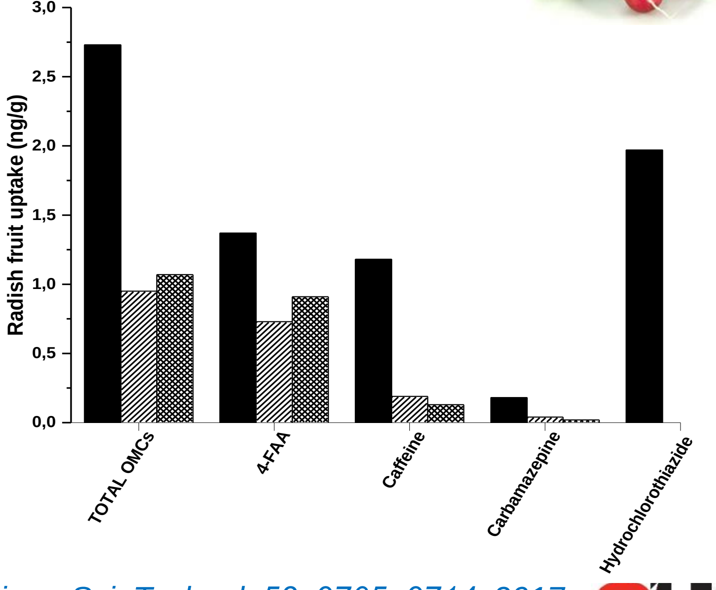
Fig. 2. Heat map showing the potential of the main crop species for CECs uptake. The highest potential for uptake is indicated with dark red; the lowest potential with dark green.

A. Christou et al. Environmental Research 170 (2019) 422–432

Subtask B – Results of D. B5

Concentration (ng/g) of target analytes found in lettuces and radish fruit irrigated with untreated and treated UWW with solar processes, solar/H_2O_2 and solar photo-Fenton.





Aguas et al., Environ. Sci. Technol. 53, 9705−9714, 2017

Subtask B – Results of D. B5

New EC regulation on water reuse

Table 1 Classes of reclaimed water quality and allowed agricultural use and irrigation method

L 177/32 EN Official Journal of the European Union 5.6.2020

REGULATION (EU) 2020/741 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 25 May 2020

on minimum requirements for water reuse

(Text with EEA relevance)

Article 2

Scope

1. This Regulation applies whenever treated urban waste water is reused, in accordance with Article 12(1) of Directive 91/271/EEC, for agricultural irrigation as specified in Section 1 of Annex I to this Regulation.

2. A Member State may decide that it is not appropriate to reuse water for agricultural irrigation in one or more of its river basin districts or parts thereof, taking into account the following criteria:

(a) the geographic and climatic conditions of the district or parts thereof;

(b) the pressures on and the status of other water resources, including the quantitative status of groundwater bodies as referred to in Directive 2000/60/EC;

(c) the pressures on and the status of the surface water bodies in which treated urban waste water is discharged;

(d) the environmental and resource costs of reclaimed water and of other water resources.

Any decision taken pursuant to the first subparagraph shall be duly justified on the basis of the criteria referred to in that subparagraph and submitted to the Commission. It shall be reviewed as necessary, in particular taking into account climate change projections and national climate change adaptation strategies, and at least every six years taking into account river basin management plans established pursuant to Directive 2000/60/EC.

...ts for agricultural irrigation

Minimum quality class							TSS (mg/l)g/l)	Turbidity (NTU)U)	Other
A									
B									
C	Food crops consumed raw where the edible part is	Drip irrigation** or	A	Secondary	≤10	≤10	≤10	≤5	*Legionella* spp.: <1,000 cfu/l where there is risk of aerosolization
D						According to Council Directive 91/271/EEC[1] ((Annex I, Table 1)	According to Directive 91/271/EEC ((Annex I, Table 1)	-	Intestinal nematodes (helminth eggs): ≤1 egg/l for irrigation of pastures or forage
								-	
								-	

[1] Council Directive 91/271/EEC of 21 May 1991 concerning urban waste water treatment (OJ L 135, 30.5.1991, p. 40).

It will enter into force on June 2023

Courtesy of Pedro Simón: ESAMUR (Murcia, Spain)

Subtask B – Results of D. B5

New EC regulation on water reuse

Table 4 Validation monitoring of reclaimed water for agricultural irrigation

Reclaimed water quality class	Indicator microorganisms (*)	Performance targets for the treatment chain ($\log_{10}$ reduction)
A	*E. coli*	≥ 5.0
	Total coliphages/ F-specific coliphages/somatic coliphages/coliphages(**)	≥ 6.0
	Clostridium perfringens spores/spore-forming sulfate-reducing bacteria(***)	≥ 4.0 (in case of *Clostridium perfringens* spores) ≥ 5.0 (in case of spore-forming sulfate-reducing bacteria)

(*) The reference pathogens *Campylobacter*, Rotavirus and *Cryptosporidium* can also be used for validation monitoring purposes instead of the proposed indicator microorganisms. The following $\log_{10}$ reduction performance targets should then apply: *Campylobacter* (≥ 5.0), Rotavirus (≥ 6.0) and *Cryptosporidium* (≥ 5.0).

(**) Total coliphages is selected as the most appropriate viral indicator. However, if analysis of total coliphages is not feasible, at least one of them (F-specific or somatic coliphages) has to be analyzed.

(***) *Clostridium perfringens* spores is selected as the most appropriate protozoa indicator. However sporeforming sulfate-reducing bacteria is an alternative if the concentration of *Clostridium perfringens* spores does not allow to validate the requested log10 removal.

Also risk assessment is required, but it´s not currently defined

Courtesy of Pedro Simón: ESAMUR (Murcia, Spain)

SOLAR HEATING & COOLING PROGRAMME INTERNATIONAL ENERGY AGENCY

Subtask C: System integration and decision support for end user needs

Main Results & Their Importance

Subtask C – project team

Prof Mikel C Duke – Subtask Leader

- Victoria University

Dr Wei Yang

- University of Melbourne

Mr Mahdi Shahrooz

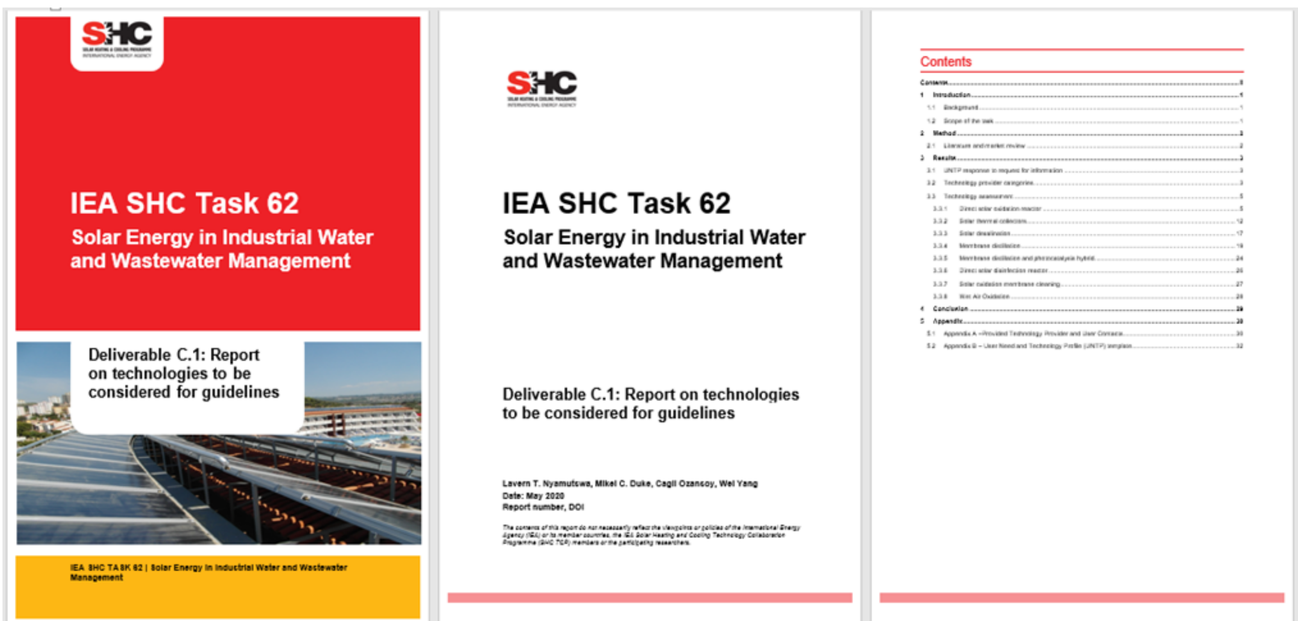
- Victoria University (intern)

Ms Maedeh Nadimi

- Victoria University (intern)

Subtask C – Results of D. C1

- Technology Review final draft completed
- Report on technologies to be considered for guidelines



Subtask C – Results of D. C1

Examples from 18 technologies in 9 categories

TRL3-TRL9

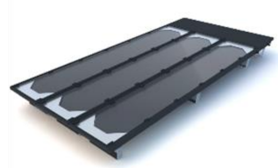
Solar thermal panels

Absolicon, Sweden

3F Solar, Austria

Trivelli Energia, Italy

Solar thermal desalination



SOLARDEW
CLEAN WATER SOLUTIONS

Solardew, The Netherlands

F Cubed, Australia

Membrane distillation

Aquastill, The Netherlands

Wet air oxidation

PSA, Spain

Direct solar oxidation/ disinfection

U Salerno, Italy

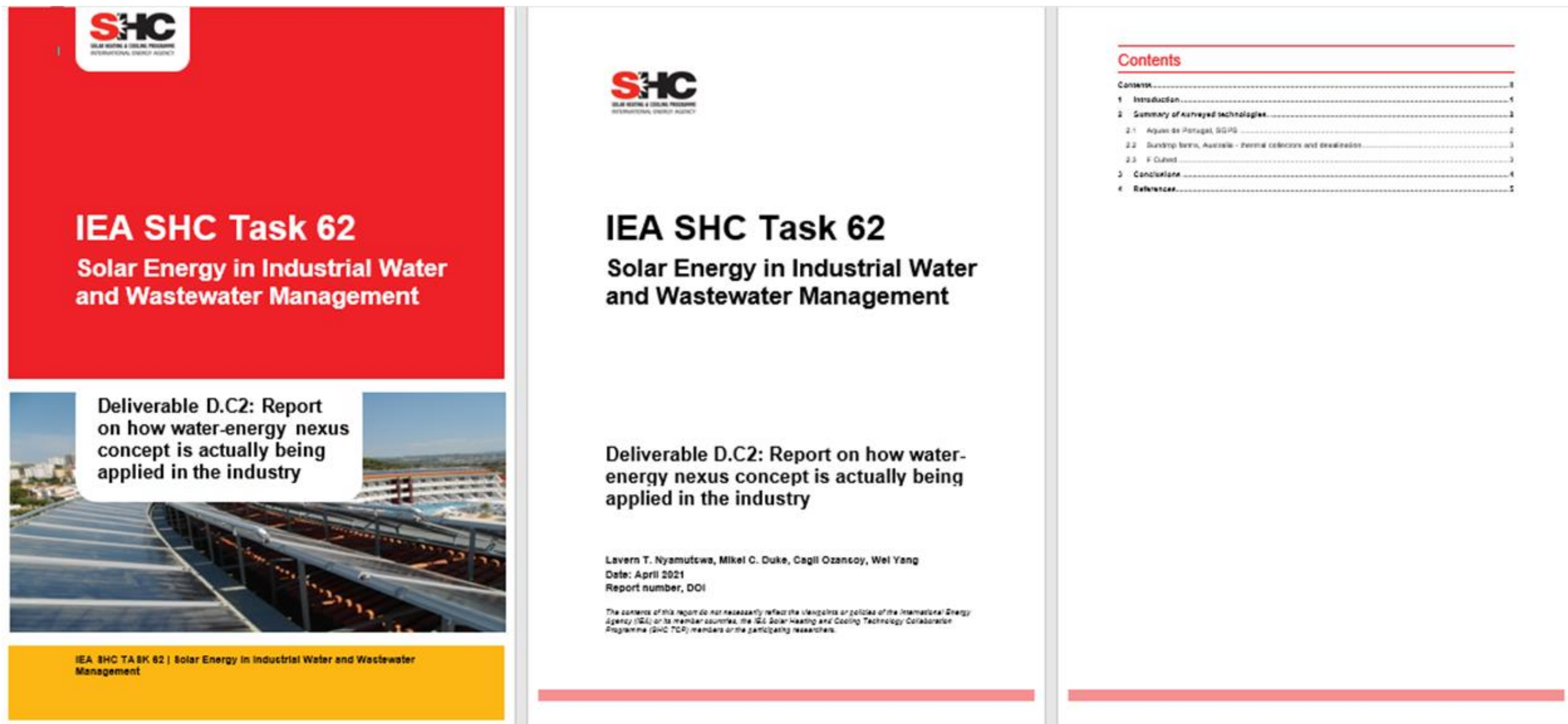
PSA, Spain

CIESOL, Spain

Subtask C – Results of D. C2

Report on how water-energy nexus concept is actually being applied in the industry

Status: Final draft submitted



IEA SHC Task 62

Solar Energy in Industrial Water and Wastewater Management

Deliverable D.C2: Report on how water-energy nexus concept is actually being applied in the industry

IEA SHC TASK 62 | Solar Energy in Industrial Water and Wastewater Management

IEA SHC Task 62

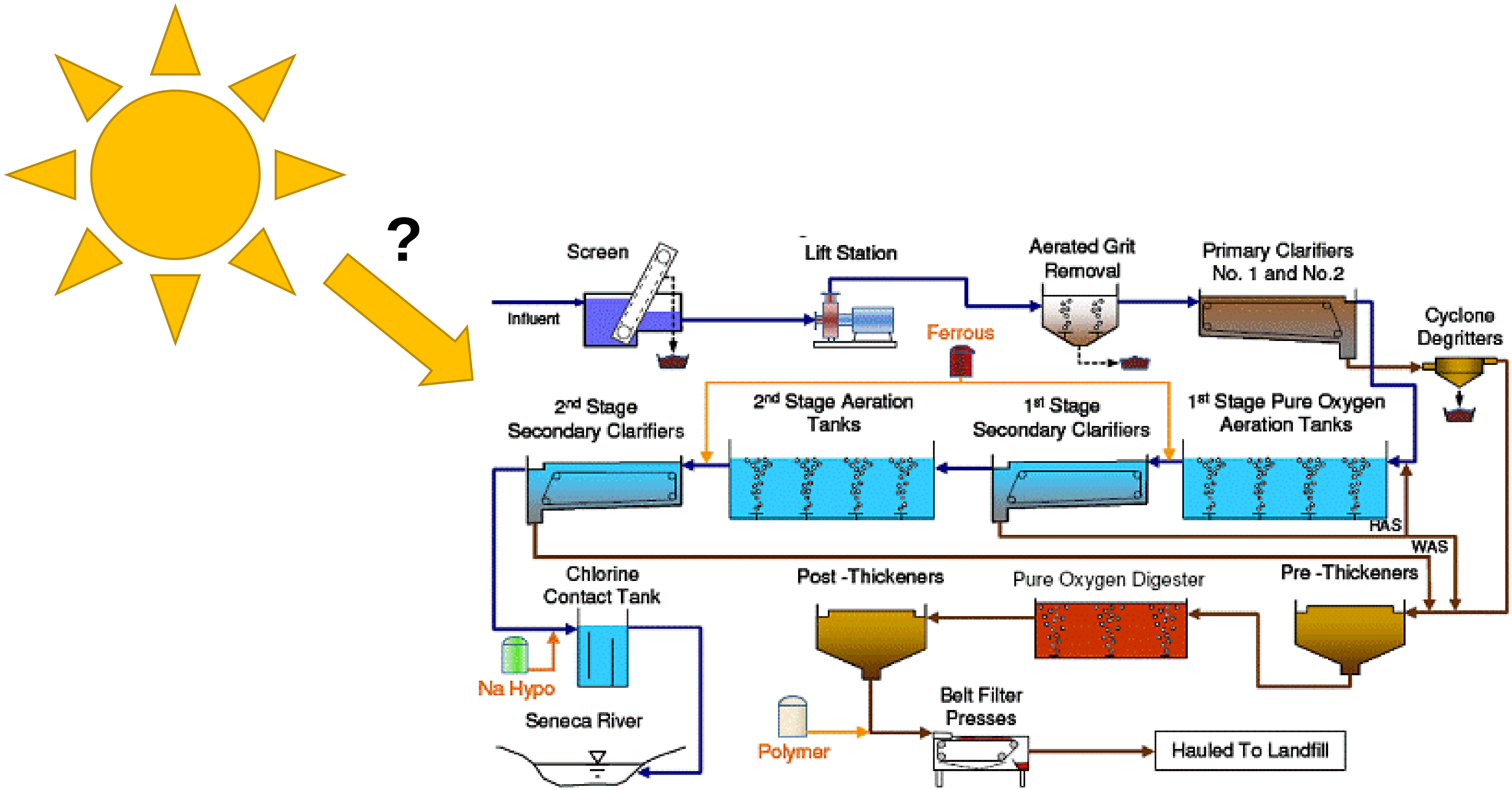
Solar Energy in Industrial Water and Wastewater Management

Deliverable D.C2: Report on how water-energy nexus concept is actually being applied in the industry

Lavern T. Nyamutswa, Mikel C. Duke, Cagil Ozansoy, Wei Yang
Date: April 2021
Report number, DOI

Contents

Subtask C – Results of D. C2

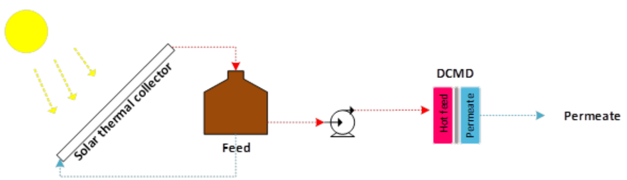


Subtask C – Results of D. C2

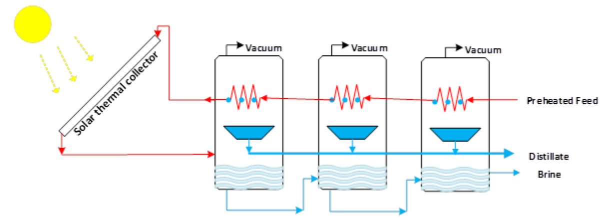
Process	Description	Integrated with Solar thermal or photon
Screening	Screening is the first unit operation used at wastewater treatment plants (WWTPs) for removing objects (e.g., plastics, rags).	✘
Grit removal	Grit removal system is used to remove Grit (e.g., sand, gravel, and heavy solid materials).	✘
Sedimentation	Sedimentation removes settleable organic and floatable solids. Normally, 90 to 95% settleable solids, 40 to 60% TSS, and 25 to 35% BOD is removed using this process.	✘
Coagulation and flocculation	Coagulation and flocculation destabilize dispersed particles, agglomerates, and particulate matter. This is especially the case when attempting to remove particles of less than 50 µm in diameter.	✘
Clarification	Clarification removes suspended solids through gravity settling.	✘
Flotation	Flotation separates solid particle or liquid droplets from a liquid phase. Its main advantage over sedimentation is the removal of small or light particles, which settle slowly.	✘
Softening	Softening reduces the hardness of water by various processes such as chemical precipitation and ion exchange. It can increase the lifetime of heat exchangers and reduce the encrustation of pipes.	✘
Filtration	Filtration reduces/removes particles dispersed in liquids. It involves using a filter (such as a membrane, or a packed bed filter) to reject the unwanted substances/contaminants while others pass through the pores of the filter.	✘
Desalination	Desalination can be performed through two technologies: thermal desalination and membrane desalination. A few examples of large-scale thermal desalination technologies include multi-stage flash distillation (MSF), and multi-effect distillation (MED). A few instances of desalination technologies include reverse osmosis (RO), membrane distillation (MD).	✓
Nutrients and organic removal/destruction	It can be performed biologically or using photocatalysis. The biological nutrients and organic removal process removes organics, nitrogen and phosphorus from wastewater using microorganisms. In photocatalysis, catalysts are used to absorb the light to initiate the chemical reactions.	✓ **Photocatalysis**
Disinfection	Disinfection destroys or removes the pathogens. There are three main types of disinfection namely, heat treatment, ultraviolet radiation, and chemical treatment (using oxidizing agents such as chlorine and ozone)	✓
Adsorption	Adsorption removes organics that are not removed by other processes. It can also be utilized for dechlorination of wastewater before final discharge.	✘
Aeration	Aeration removes volatile organic chemicals, dissolved gases; and oxidizes iron and manganese.	✘

Subtask C – Results of D. C2

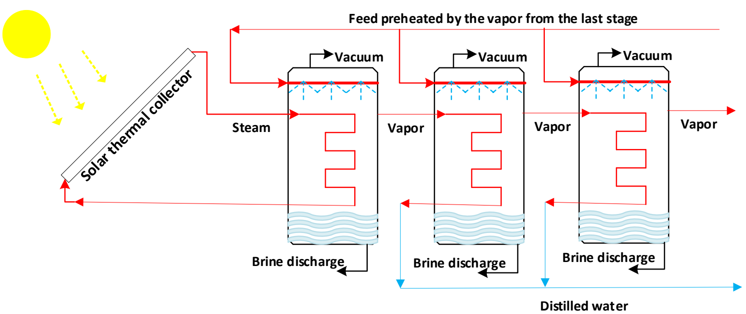
Solar-powered MD



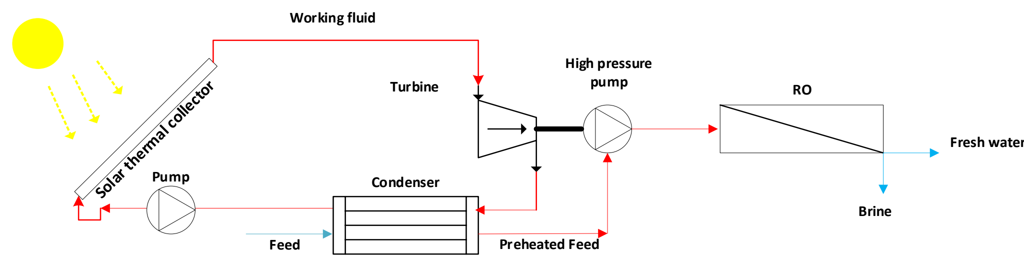
Solar-powered multi-stage flash (MSF) distillation



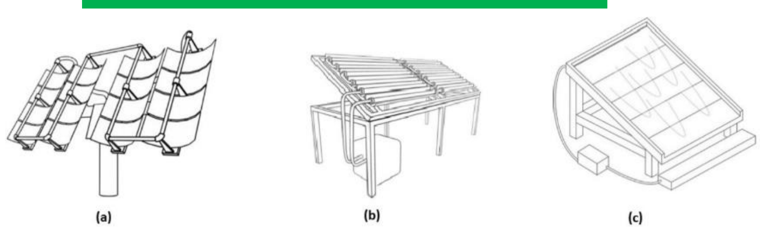
Solar-powered multi-effect distillation (MED)



Solar-powered reverse osmosis (RO)

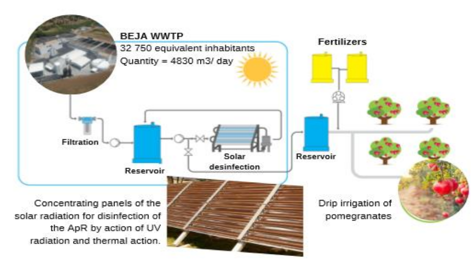


Solar Photocatalysis



Schematic of three different photoreactors: a) PTC, b) CPC and c) IPC

Solar disinfection



Subtask C-Results of D. C2

www.sundropfarms.com

Select only user adopted cases of solar thermal+water treatment

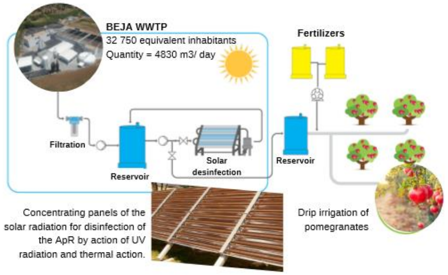
Solar thermal desalination

- Sundrop Farms, Australia (agricultural production)
- F Cubed solar stills, Australia (clean water for small/remote communities)

http://www.fcubed.com.au/

Solar disinfection of wastewater for agricultural irrigation

- Águas de Portugal for irrigation of Pomegranate



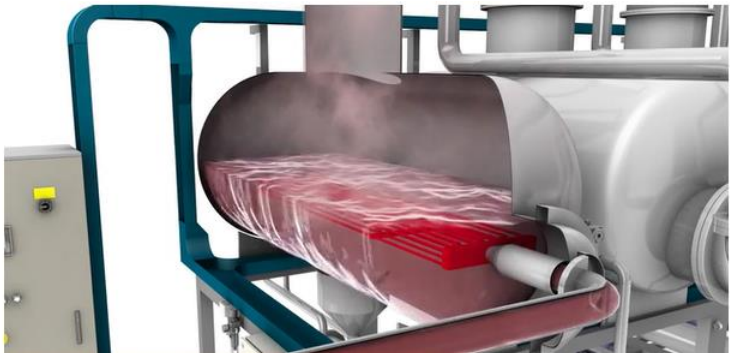
https://www.adp.pt/en/

Subtask C- Results of D. C2

Small number of industry led examples

Trials underway (practical value TBC)

Solarvap
(solar-powered evaporation system that produces distilled water)



The first unit of solar evaporation system designed by Condorchem Envitech. (Image taken from Solarvap Video link: https://www.youtube.com/watch?v=4E-KFkH_IF4&feature=youtu.be)

Flamingo
(launched in Australia as a solar-powered water treatment technology)

The Flamingo water treatment unit uses highly reflective curved mirrors to focus solar irradiation to produce distilled water and to obtain a dry slurry output.

Reflective curved mirrors (Snapshot photo taken from JWA video: https://youtu.be/mDWDKfC5Zdk)

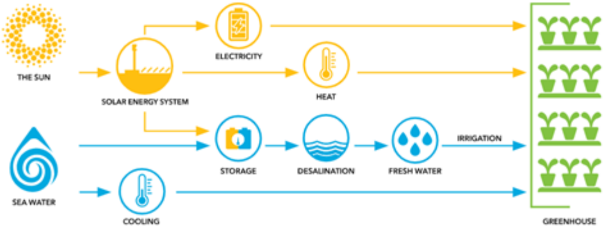
Subtask C – Results of D. C2

Key findings – purpose of selection of solar water treatment:

1. Lack of availability of fresh water, and abundance of impaired water source;
2. Direct demonstration of value from system output (including the water itself, agricultural output);
3. Fit for purpose technology complexity;
4. Assurance/control of the quantity and quality of the water supplied; and
5. Apparently best technology option, where solar availability is first factor, while other selection factors include relative simplicity and scalability.

<u>For large scale thermal, simultaneous heat generation may have been a deciding factor</u>

<u>Small scale: simplicity</u>



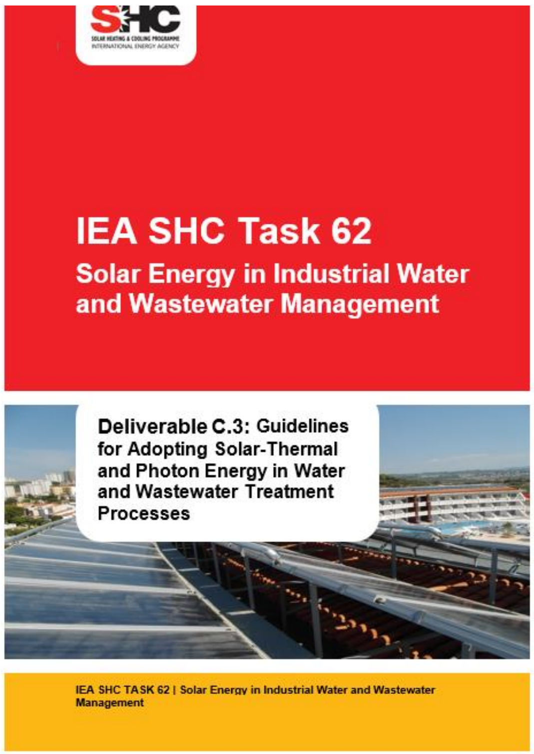
http://www.fcubed.com.au/ www.sundropfarms.com

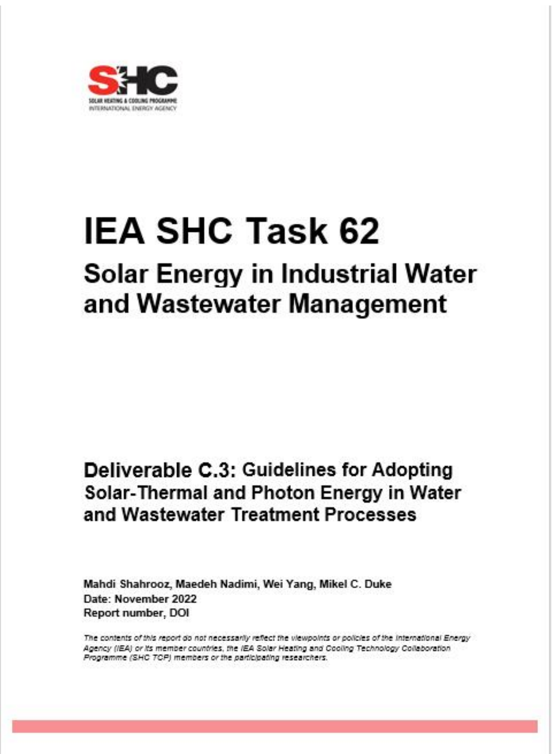
SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Subtask C – Results on D. C3

Guidelines for Adopting Solar-Thermal and Photon Energy in Water and Wastewater Treatment Processes

Status: First draft submitted





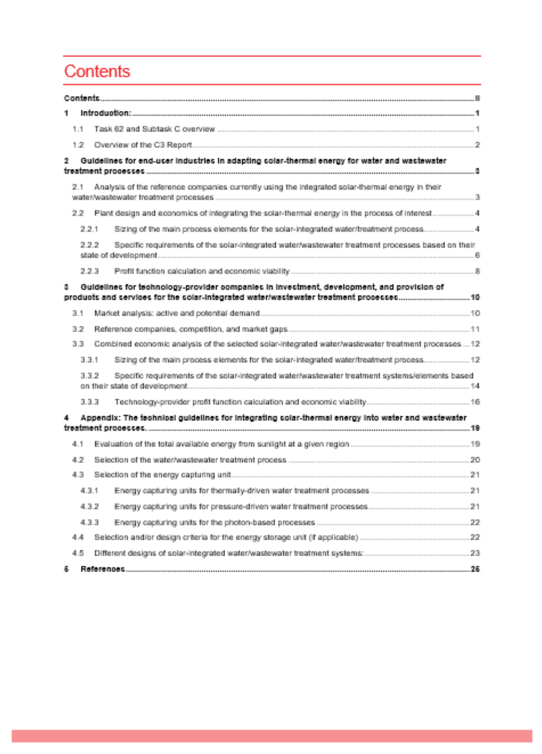
IEA SHC Task 62

Solar Energy in Industrial Water and Wastewater Management

Deliverable C.3: Guidelines for Adopting Solar-Thermal and Photon Energy in Water and Wastewater Treatment Processes

Mahdi Shahrooz, Maedeh Nadimi, Wei Yang, Mikel C. Duke

Date: November 2022
Report number, DOI



Contents

Subtask C – Results on D. C3

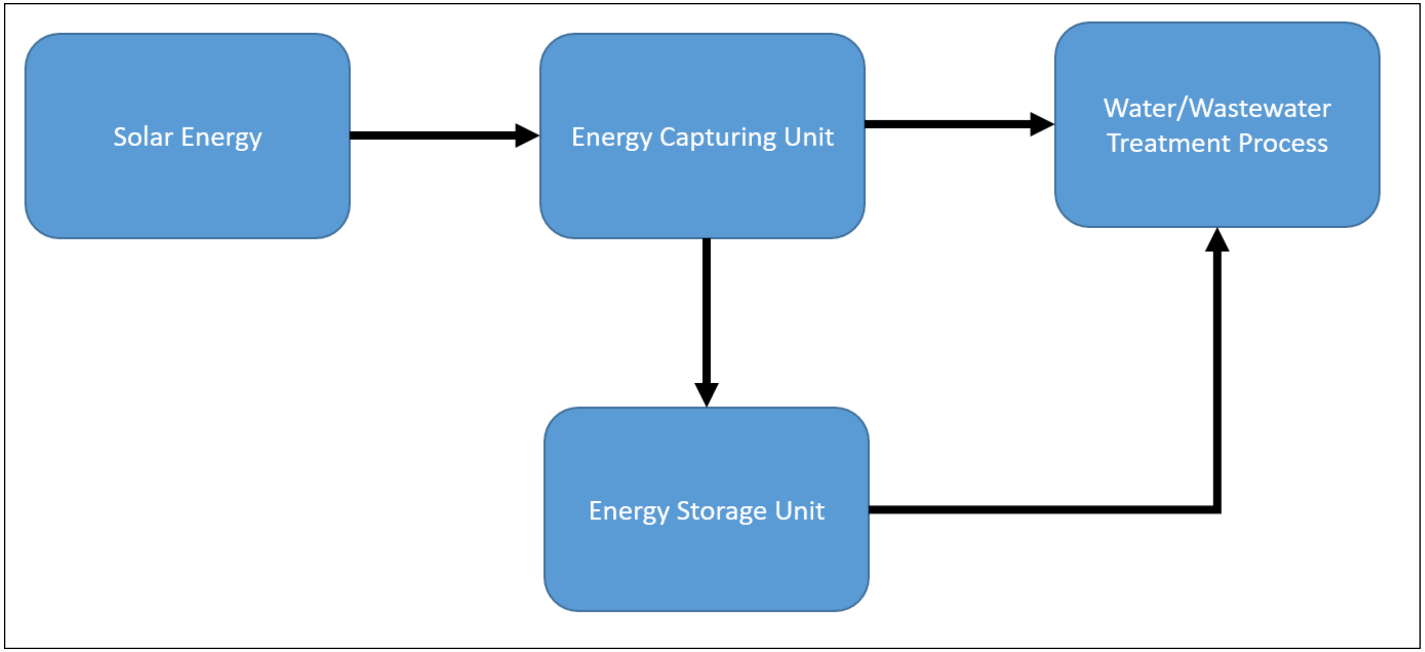
Guidelines to assist at high level – refers to C1 and C2

- Guidelines for end-user industries in adopting solar-thermal energy for water and wastewater treatment processes
  - 1.1. Analysis of the reference companies
  - 1.2. Plant design and economics of the integrated process
  - 1.3. Sizing of the main process elements and cost estimation of the solar-integrated process
  - 1.4. Specific requirements of the solar-integrated water/wastewater treatment processes based on their state of development (technology readiness (TR) Level)
  - 1.5. Profit function calculation and economic viability
- Guidelines for technology-provider companies also developed
  - Similar outline to end user industries

Subtask C – Results on D. C3

Appendix: Technical guidelines for integrating solar-thermal energy into water and wastewater treatment processes

The four main elements of solar-thermal-integrated water treatment processes



Reports, Published Books & Online Tools

Author(s)/ Editor	Title	Report No. AND Publication Date (month, year)	Target Audience	Web or Print AND “RE” if restricted access*
Subtask C team	Technology list - Part B of Solar water treatment user need technology template (UNTP) form	1st April 2019	Technology providers or researchers	Web/Mail
Book editors: T.-S. Chung and K.-J. Lu / Chapter authors: M. C. Duke and N. Dow	Book title: Membrane distillation: membranes, hybrid systems and pilot studies, Chapter title: Membrane Distillation for Industrial Water Treatment: Experiences from Pilot Trials. Membrane distillation: membranes, hybrid systems and pilot studies	2019	Technology providers, researcher and appliers	Publisher: Taylor & Francis
Book editors: Y. M. Lee and E. Drioli. Chapter authors: M. Duke and X. Yang	Book title: Membrane Distillation: Materials and Processes. Chapter title: Economic Analysis of Membrane Distillation	2020	Technology providers, researcher and appliers	Publisher: Nova Scientific Publishers
Malato S., Oller I., Polo I., Fernández-Ibañez P.	Solar Detoxification and Disinfection of Water. In: Meyers R.A. (eds) Encyclopedia of Sustainability Science and Technology.	Springer, New York, NY. https://doi.org/10.1007/978-1-4939-2493-6_686-3	Academic	Web

Other Dissemination Activities

- **8 Conference papers**
- **31 Conferences presentations/posters**
- **22 Journal articles and other publications**
- **6 Task organized workshops/seminars**
- **1 Solar Academy webinar**

Task Work: Main Accomplishments

- Identification of industry sectors and processes with high potential for solar driven water purification
- Collection of information from experts and compile into summary reports to capture state of the art in solar thermal water treatment with practical potential
- Connecting experts around the world and different areas and disciplines and starting of a expert network
- Identification of gaps/needs for further application of solar thermal/photon adoption by industry

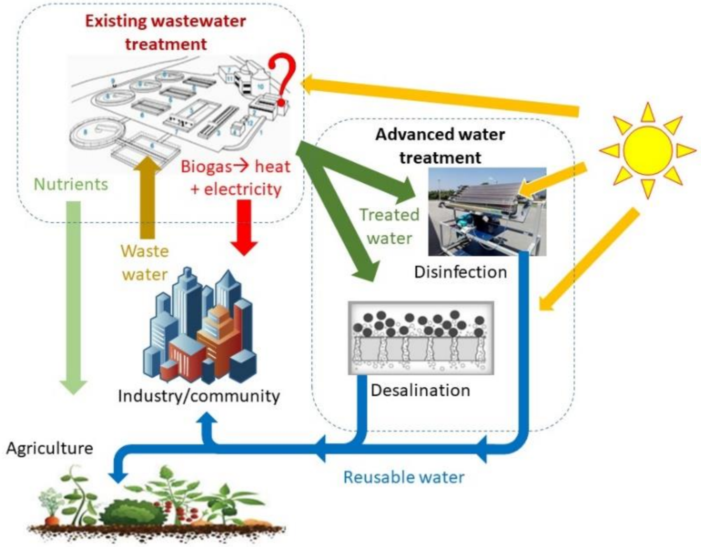
Task Work: Lessons Learned

- Strong interest from water industry in solar technologies for water treatment
- Major efforts in research for solar thermal water treatment, relatively small pickup in industry
- Though solarthermal collectors (flat plate, evacuated tube) achieve desired temperatures for separation processes, there is still great potential here for solar collector manufacturers to expand their product range and offer customized solutions
- PV and grid renewables current major focus for separation technologies

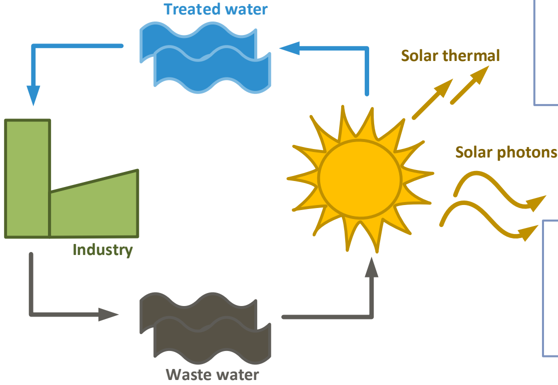
Task Results: Key Messages

- **#1** Technologies that fulfil several functions, such as the purification of wastewater and simultaneous conversion of the organic components into hydrogen and green gas by means of photocatalytic conversion, have great future potential.
- **#2** Solar thermal water treatment will find major application initially in small scale/remote applications and/or regions with reliable sunshine and abundant supply of impaired water (seawater or wastewater)
- **#3** The integration of water treatment technologies into a solar collector in the sense of process intensification would represent an increase in efficiency in terms of energy supply and treatment performance.

Task Results: Key Visuals



(www.https://www.adp.pt/en/)



Membrane distillation, Pervaporation, Vacuum evaporation, Rectification, Humidification-Dehumidification,…

Photoctalytic Water Decontamination and Disinfection Systems

Future Work

Areas for Future Work

- **#1** New materials and coatings for thermally driven water separation membranes to advance their long-term, selectivity and efficient use for various industrial applications
- **#2** New solar collector concept to merge solar supply and a reactor for water separation and treatment processes. For the solar industry there is the possibility to bring own products to the market for 1) thermal and 2) photon water treatment, opening up also the potential for creating new energy vectors (e.g., H_2).
- **#3** Demonstrations led by industry. There is a large availability of technologies from companies, and great depth of research knowledge. However the next step to realization is with more industry led examples.

Task Management

Overall Conclusions

- There is definitely a high potential for solar thermal industry and water treatment processes
- Need of upscaling and more best practice examples
- Solar thermal companies should have the courage to develop new products such as combined collectors with membrane separation processes or solar reactor
- For pure system integration, e.g. for evaporation plants, solar thermal energy is in strong competition with waste heat and electricity-based technologies such as PV
- Due to Corona and the online meetings it was a challenge to build up a strong expert community

Recommendations

- For ExCo
  - More financial support for the Experts and if support is provided, then the results should also be prepared nationally by the experts – good national exchange
- For future OAs
  - Take time for the Task preparation and define not too many deliverables

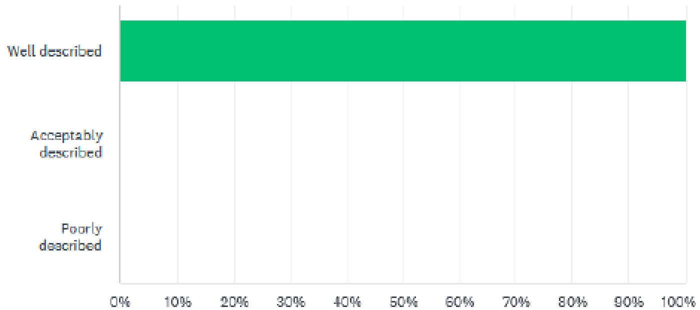
Final Task Evaluation

Final Task Evaluation Summary

Q1

Were the objectives, milestones, results and expected impacts of the Task work well described in the beginning of the Task?

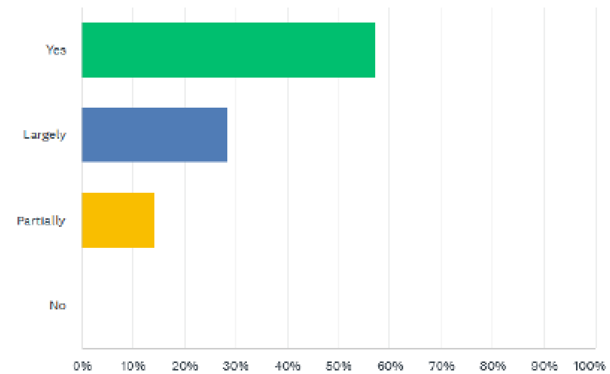
Beantwortet: 7 Übersprungen: 0



Q2

Was the approach used to accomplish the Task work logical and appropriate?

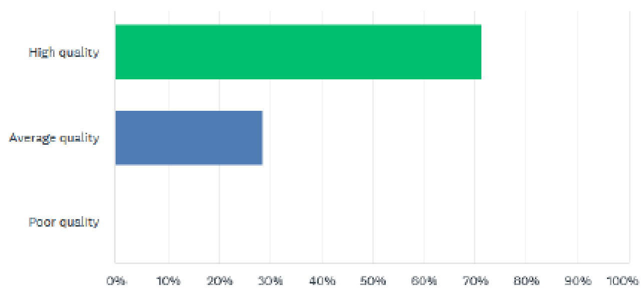
Beantwortet: 7 Übersprungen: 0



Q3

What is the scientific quality of the Task work?

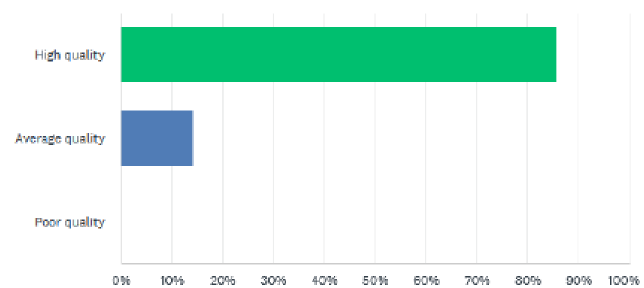
Beantwortet: 7 Übersprungen: 0



Q4

What is the technical quality of the completed Task products?

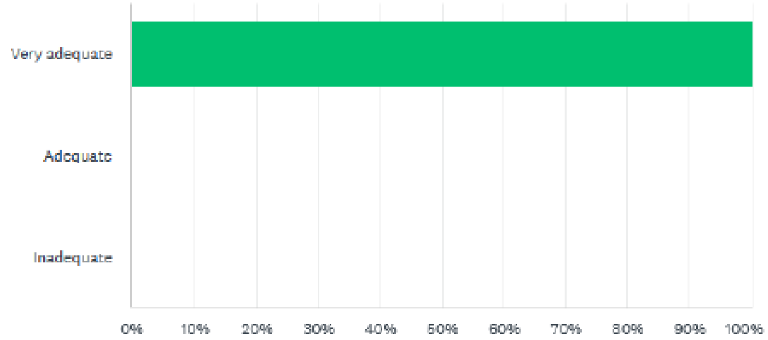
Beantwortet: 7 Übersprungen: 0



Q5

Was the level of effort of the Task Manager adequate to complete the Task?

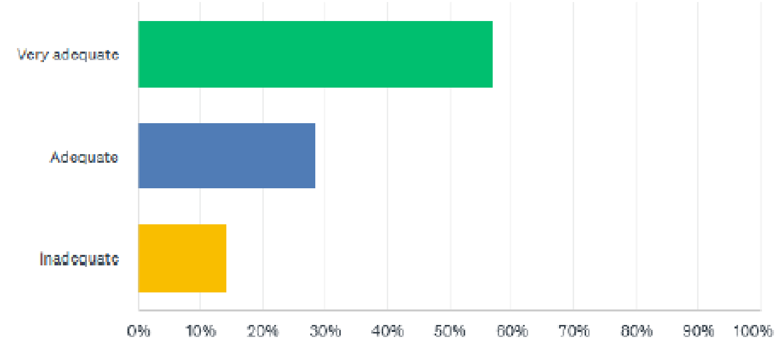
Beantwortet: 7 Übersprungen: 0



Q6

Was the level of effort of the active experts adequate to complete the Task?

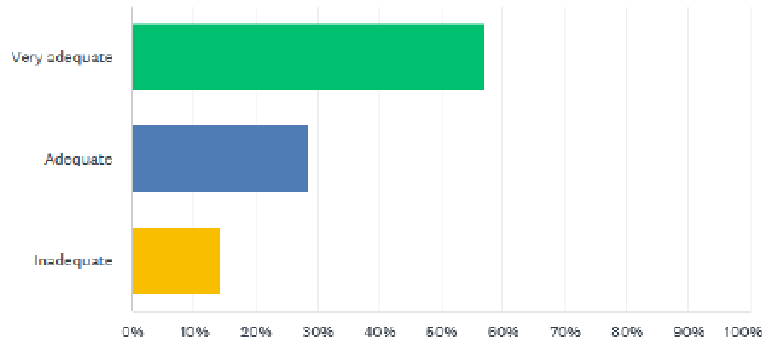
Beantwortet: 7 Übersprungen: 0



Q7

Was the level of effort of the Subtask A Leader adequate to complete the Task?

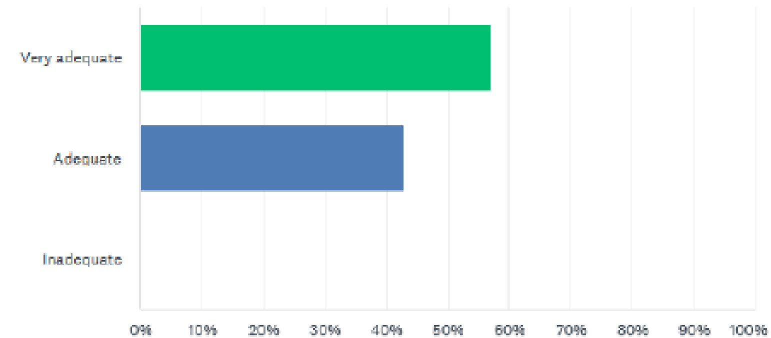
Beantwortet: 7 Übersprungen: 0



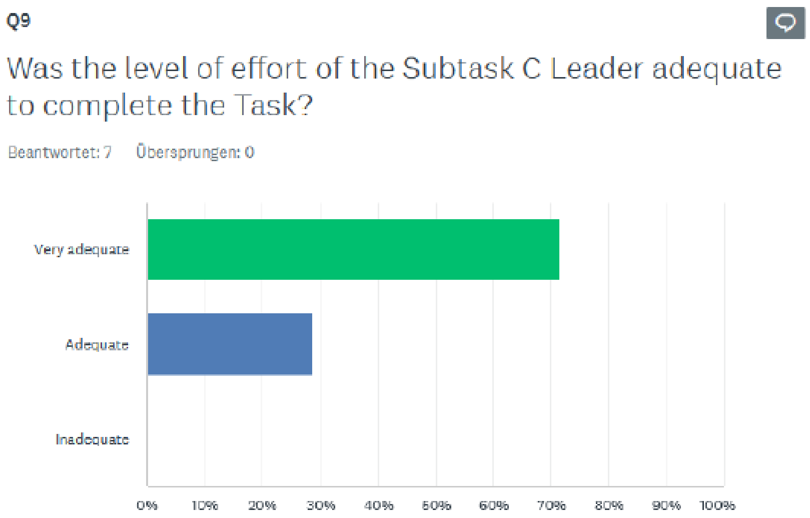
Q8

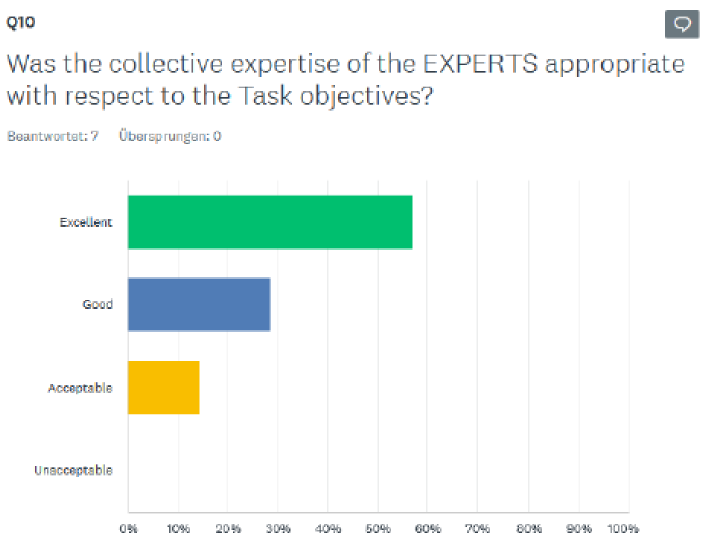
Was the level of effort of the Subtask B Leader adequate to complete the Task?

Beantwortet: 7 Übersprungen: 0



Final Task Evaluation Summary





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