RESEARCH ARTICLE | SEPTEMBER 29 2017

A mini review on the integration of resource recovery from wastewater into sustainability of the green building through phycoremediation

Anie Yulistyorini

AIP Conf. Proc. 1887, 020048 (2017)
https://doi.org/10.1063/1.5003531

A Mini Review on the Integration of Resource Recovery from Wastewater into Sustainability of the Green Building Through Phycoremediation

Anie Yulistyorini[1,a)]

[1] Department of Civil Engineering, Faculty of Engineering, State University of Malang, Malang, Indonesia

[a)]Corresponding author: anie.yulistyorini.ft@um.ac.id

Abstract. Green building implementation is an important assessment for sustainable development to establish a good quality of the environment. To develop the future green building implementation, resource recovery from the building wastewater is significantly important to consider as a part of the green building development. Discharge of urban wastewater into water bodies trigger of eutrophication in the water catchment, accordingly need further treatment to recover the nutrient before it is reused or discharged into receiving water bodies. In this regard, integration of microalgae cultivation in closed photobioreactor as building façade is critically important to be considered in the implementation of the green building. Microalgae offer multi-function as bioremediation (phycoremediation) of the wastewater, production of the biofuels, and important algal bio-products. At the same time, algae façade boost the reduction of the operating cost in forms of light, thermal energy and add the benefit into the building for energy reduction and architecture function. It promises an environmental benefit to support green building spirit through nutrient recovery and wastewater reuse for algae cultivation and to enhance the aesthetic of the building façade.

INTRODUCTION

Worldwide, Indonesia is the fourth of the most populous country with approximately 263 million people in 2017 and the density of 146/km^2 in which more than half of the total population live in Java Island [1]. In 2014, it was reported that the Indonesian economy was stable towards the increased growth of population [2]. Based on the main economic indicators reported by Bank Indonesia Finance Department of Republic of Indonesia in 2009, the economic growth of 4% was followed by the increase of 9% in construction sectors including residential and non-residential [2]. The increase of the construction activities in Indonesia will also be followed by the rise of the environmental impact in which occurs through the whole cycle of the construction to the final demolition. Even though the development of the construction project has significantly contributed to the economic and social development, it is also associated with deterioration of the environmental quality [3, 4] due to the use of materials, energy, land, biodiversity, and water [5].

In addition to the construction industry, 40% of the global energy production, 40% of the raw materials, and 25% of the timber have consumed for this sector. This activity consumes about 12-16% of fresh water, generate 40% of solid waste, and emit approximately 30%-40% of greenhouse gases [6-9]. As a result, it has been increased in a global awareness of the sustainability aspect in the construction industry [8].

In regard to the environmental problem, it is recognized that green building (GB) is an environment effectively approach for sustainable development in the construction field [10, 11]. Thus, the major characteristics of GB also comprise of the environment and human health consideration, adequacy of the natural and material resources requirement, and efficiency use of the water and energy requirement [12]. A comprehensive literature about GB has conducted by Darko and his co-worker and they identified the important drivers which influence the stakeholders to

Green Construction and Engineering Education for Sustainable Future
AIP Conf. Proc. 1887, 020048-1–020048-10; doi: 10.1063/1.5003531
Published by AIP Publishing. 978-0-7354-1570-6/$30.00

implement GB approach to the construction industries [6]. Those are an external drivers (e.g. government, trade union, UN) [9, 13], corporate-level driver (e.g. real estate investor) [14], property-level drivers (e.g. increased property value, high rental income, and reduced risk) [15, 16], project-level drivers (e.g. academic studies), and individual-level drivers (e.g. human behaviour) [17]. In this study, the US, UK, and Australia are the leading countries which implement GB concept followed by China and India in Asia.

In addition to the energy performance, the reduction of the energy requirement and the introduction of the renewable energy is extremely important to reach zero- energy level [9]. This issue has triggered the researcher to comprehensively study for improving the performance of the energy, and implemented renewable energy in the building. For instance in Malaysia, the fossil-fuel consumption has reduced by 10% since 2012, and currently, the country relies on hydroelectric and solar resources, and the addition of biomass and biogas to support the energy requirement [18]. In OECD countries, most of the commercial and residential building acquire approximately 35% of energy consumption, and therefore the potential of the energy saving regulation would greatly contribute to widely reduce the energy utilization [12].

It is also reported that the construction industries have contributed to the decreasing of the public health and the environmental quality due to the production of toxic waste and pollutant during the construction period [11]. Consequently, integrated and comprehensive method during the lifetime of the construction phase must be referred to the sustainability concept and the environmental impact assessment [11, 19]. Because the evaluation is an important assessment for the future building policies to promote a healthy environment [20]. In this regard, water conservation also becomes a significant consideration of the green building aspect [21]. Water conservation is the most critical issue worldwide and it is playing an important role for fundamental needs of human and ecology. However, the availability of freshwater prone to decrease due to the escalation of the global population and the climate change [21]. Hence, the preserving of water during the lifecycle of the building could contribute to the development of the green building approach [7].

Considering the approach of the future sustainable building, a concept of resource recovery from generated wastewater in the particular building is significantly important to be implemented as a part of the green building development. In order to implement a green building concept, a closed loop of wastewater recycling in forms of resource recovery in the building is very important [22, 23]. Although various studies have shown that wastewater recycling in several building types is feasible [21-25], resource recovery from wastewater through photosynthesis microorganism which integrated into building component for aesthetical purposes is still new and need further study. In particular of Indonesia, the resource recovery from wastewater which generated from the building activities is urgent to be handled which otherwise cause deteriorating of the environment. This study is aimed to review various research works which related to the integration of resource recovery in the building. The review focuses on the resource recovery from wastewater through phycoremediation and its possible application in the green building façade for the architecture purposes

COMPOSITION OF MUNICIPAL WASTEWATER

Water bodies have received untreated wastewater from different sources (e.g. point-source and non-point source) which vary in concentration and volume [26]. The life styles types, the use of the technologies practiced in the society, and the income level indicate the chemical content of the untreated wastewater [27, 28]. The wastewater composition is very complex because it consists of organic, inorganic, and synthetic compound [26]. This composition commonly consists of water and less amount of solids in which 70% and 30% of solids represent of the organic and inorganic materials, respectively [29]. Mara described the composition of domestic wastewater in Figure 1 [29], and the largest proportion of organic matter in the domestic wastewater was fibers at 20.64%, followed by proteins and sugars at 12.38% and 10.65%, respectively [30]. This composition effect on the selection of an appropriate wastewater treatment process before designing wastewater treatment plant [31], whether the wastewater will be treated through physical, chemical or biological treatment [20].

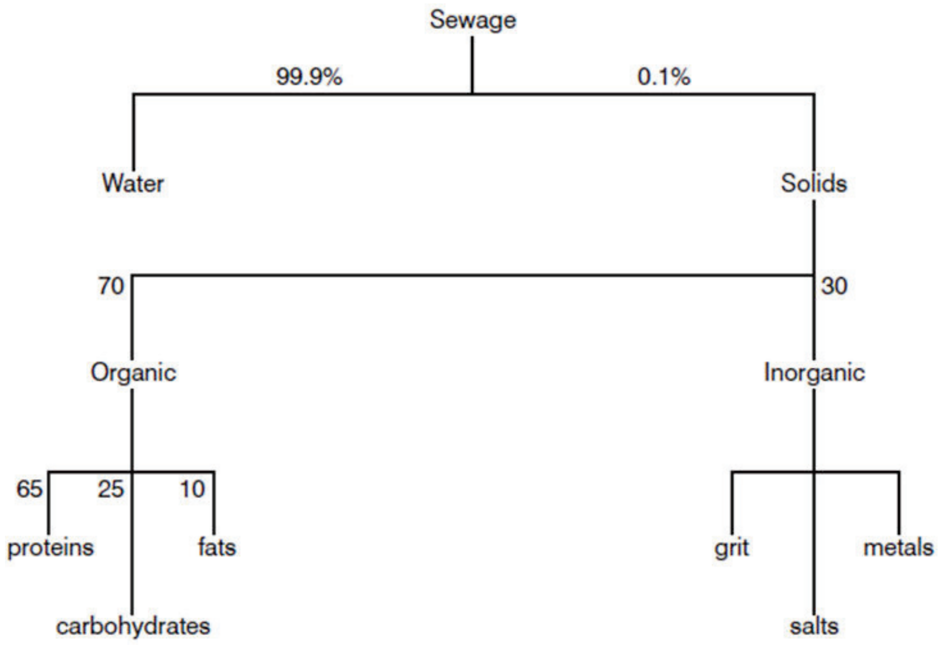


FIGURE 1. Domestic wastewater composition [29]

SUSTAINABLE WASTEWATER TREATMENT APPROACHES

Worldwide, wastewater treatment is categorized as centralized or decentralized approaches [32]. Centralized treatment commonly implemented in the developed countries which allow the wastewater to collect through sewerage system and to treat centralized using advanced treatment technology [32], and therefore less public participation and awareness needed [33]. However, the funding available to build up the centralized wastewater treatment and the lack of the technical expertise to manage and to operate the whole system become the main issue in its implementation in developing countries [33].

Currently, on-site treatment is a common practice for domestic wastewater treatment in Indonesia. Several cities have already sewerage network (e.g. Balikpapan, Banjarmasin, Bandung, Cirebon, Jakarta, Surakarta, Tangerang, Yogyakarta, and Denpasar) for domestic wastewater treatment [34, 35]. This service is accounted for less than 1% of the Indonesian urban population, while over 70% of the urban household rely on the on-site treatment [34, 36, 37], and therefore the issue of discharging untreated wastewater from houses, business, and industries to the environment or water bodies become an important problem to be managed.

Those problems have triggered many countries including Indonesia to develop decentralized wastewater for treating the wastewater, as decentralized wastewater treatment can be implemented in the small area or even to treat wastewater in the specific location. The number of decentralized system in the developing countries appear to rise as a consequence of the United Nations Millennium Development Goals (MDG) implementation in 2015 [32]. Previous studies investigated the advantages of the decentralized wastewater treatment which consider a more sustainable approach to managing wastewater source such as in Catalonia [38], in Indonesia [39], in Zimbabwe [40], in Spain [41], and in Vietnam [42]. In particular of developing countries, the choice of a decentralized wastewater treatment is becoming an attractive method because the system is more sustainable in terms of economic, environmental, and social aspect [33]. Moreover, in sustainability perspective, resource conservation and nutrient recycling become an important component to be considered in the development of the sustainable building.

RESOURCE RECOVERY FROM WASTEWATER

Nowadays, wastewater is considered as a renewable resource as it contains organic matter, Nitrogen, Phosphorus, heavy metal, and thermal energy [43] from which the treatment of the wastewater will produce clean water, bio fertilizer, and energy [44-46]. These resources can be used to fulfill the basic need of the current global population as the world is facing to the decrease of the natural resources [47].

As an illustration, approximately 2.5 billion urban people will be added the global population in 2050, in which about 90% will be concentrated in Asia and Africa. In the next 20 years, the Indonesian population is expected to be 305 million people in which an estimate of 67% of the population will live in the cities [48-50]. This growth is becoming a crucial threat to the pressure of the finite natural resources [50], and therefore resource recovery from urban wastewater is significantly important to be managed to eliminate the environmental impact. To recover the renewable resources from the building wastewater, decentralized wastewater treatment seems more favorable to be applied as this system is more affordable for the community.

Verstraete and his co-worker identified the possibility of wastewater streams diversion into concentrated and diluted forms. They conducted the wastewater partition through filtration-based treatment, anaerobic digestion, and nutrient recovery using microorganism by enhancing the biological uptake [51]. In addition to this, the removal of nutrient and carbon from the liquid can be performed using biological agents [44], and therefore value-added organic or microbial products from the final effluent can be generated [52]. The overall process from the certain wastewater input will generate four important products such as (a) clean water effluent that meets the discharge limit (e.g. $N < 5$ mg l^{-1}, $P < 1$ mg l^{-1}) [44], (b) biogas [53, 54], (c) biosolids [55] and (d) a fertiliser streams [52]. Worldwide, approximately 20% of manufactured base-material fertilizer is recovered in urban domestic wastewater [44] and these content represent a valuable renewable material which reused in various products in the industry and in agriculture [52].

In this context microalgae offer the potential of biological resource recovery from various wastewater [56, 57] which employed many species of microalgae such as *Scenedesmus* sp. [54], *Chlorella* sp. [57], *Chlamydomonas reinhardtii* [58, 59], *Chlorella vulgaris* [60], *Auxenochlorella protothecoides* UMN280 [61], *Scenedesmus obliquus* and *Scenedesmus dimorphus* [60, 62].

Microalgae are classified as a photosynthetic microorganism that able to convert water, carbon dioxide, and light into oxygen and biomass which contain added-value products [63]. This potential showed that the algae are accounted as paramount renewable resources which provide a number of different industrial products in food commodities, biofuels, biobased chemicals, pigments, cosmetic, fine organics and pharmaceuticals [56, 64, 65]. Microalgae have also proven their ability to assimilate nutrient from numerous wastewater sources and store the nutrient in their cell for their growth [59, 66]. Thus microalgae provide a dual function not only for bioremediation from wastewater but also can produce renewable energy and valuable co-product. The potential of microalgae as biological resource recovery are described as follows:

Biofuel

Algal biomass has been considered as raw-material of biofuel production due to their ability in storing useful quantities of lipids, proteins, and carbohydrates over a short period of time [67, 68]. The main advantages of the microalgae utilisation as biofuel sources are: (1) biofuel production of the algae exceeds the yield of the most productive oilseed crops, e.g. biodiesel from microalgae yield 12,000-58,700 l ha^{-1} [67, 69] compared with 1,190 l ha^{-1} for Canola [70], 1,892 l ha^{-1} for Jatropha [71] due to the microalgae can be harvested all year round, (2) many of microalgae strains have lipids content in their cells for approximately 20%-50% of the biomass dry weight by optimising their favourable growth condition [72], (3) the algae can grow in aqueous media thus no arable land is needed. They can also cultivate in various types of wastewater [45], and therefore reducing the load of freshwater [67], (4) the microalgae fixation can utilise 1.83 kg dry weight of waste CO_2 and this can help to reduce greenhouse gases and to improve air quality [71], (5) the algal biomass can be treated to produce value-added products such as protein and fertiliser [65].

Phycoremediation

Microalgae are excellent microorganism which can effectively grow in wastewater through the assimilation of organic carbon, and inorganic N and P. This assimilation process can help the wastewater treatment plant to remove high concentration of nutrients (N and P), which otherwise will trigger the eutrophication in water bodies [73]. The potential of the microalgae as a nutrient-rich consumer is an attractive solution for sustainable and low-cost wastewater treatment [74] which is known as phycoremediation [75]. Numerous microalgae strains such as *Chlorella, Scenedesmus, Phormidium, Botryococcus, Chlamydomonas,* and *Spirulina* have been reported to effectively recover the nutrient from wastewater [57-59, 76]. Previous studies investigated that *Chlorella* and *Scenedesmus* recovered over 80% of NH_3, NO_3^-, and TP from the secondary treated sewage [62, 77], *Spirulina sp.* removed 96.5% of N and 85.92% of P from palm oil waste [45]. *Chlorella vulgaris* has been used for nutrient removal from various wastewaters with removal capacity ranging from 76% to 83% for N and from 63% to 75% for P in digested manure [78]; 55% to 88% for N and 12% to 100% for P in municipal wastewater [62]; and 30% to 95% for N and 20% to 55% for P in industrial wastewater [60]. Moreover, *C.reinhardtii* was able to remove 42%-55% of NH_4^+ and 13%-15% of P, from concentrated municipal wastewater (CMW) with an N:P ratio of 1, which means that *C.reinhardtii* has high ability to remove phosphorus from P-rich environments [58, 59]. These potential revealed that microalgae technology offer an excellent approach and appear more sustainable for wastewater bioremediation and production of the algal biomass feedstock.

Bioenergy

Bioenergy from biomass feedstock can be generated from microalgae which store high lipid and carbohydrate in their cells. Numerous of biofuels product can be formed from one microalgal biomass source [45] in several processes. The multiple processing of the microalgal biomass for bioenergy production is outlined in Fig. 2.

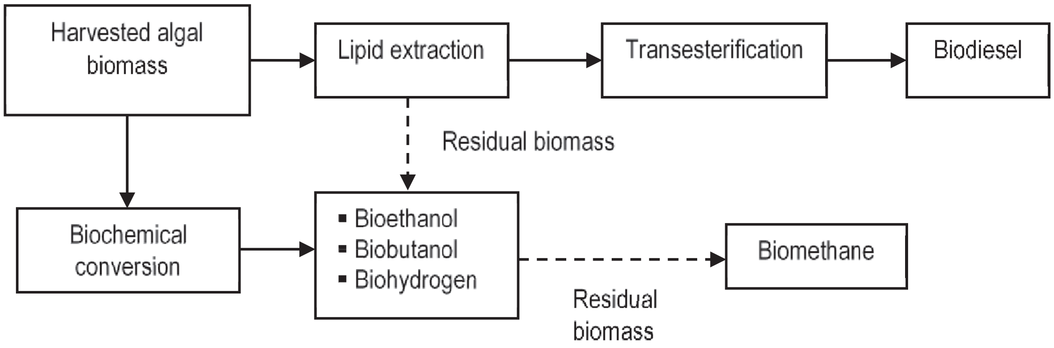


FIGURE 2. Bioenergy production from microalgal biomass processing [45]

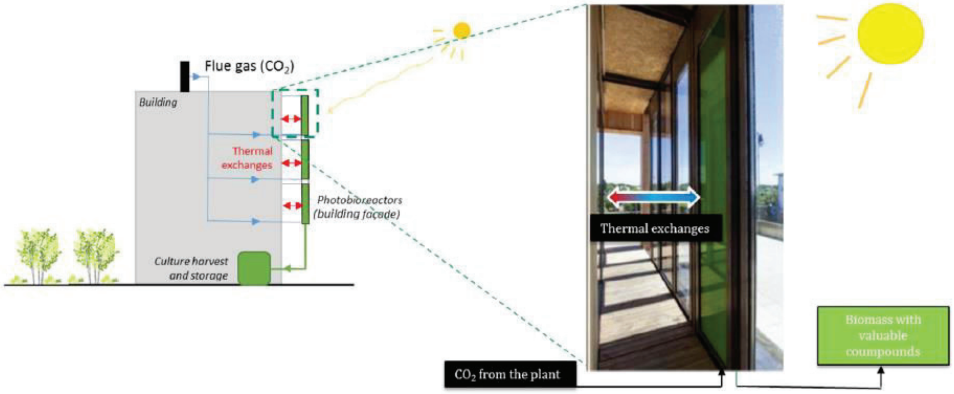
In comparison with the other common crops for oil production such as Jatropha, coconut, and oil palm, microalgae can generate 20% to 70% of oil by biomass dry weight which produces oil from 58,700 to 136,900 l ha^{-1} [71]. Microalgae present to be an excellent source of biodiesel production due to the oil content in their cells and it is possible to completely replace the fossil diesel. For instance the oil content of *Botryococcus braunii* (25%-75%), *Chlorella* sp. (28%-32%), *Nannochloropsis* sp. (31%-68%), and *Schizochytrium* sp. (50%-77%) [71].

Microalgae have proven their potential not only for biofuel but also for enhancing biogas production. Biogas production can be enhanced through the mixing of algal biomass and sewage sludge. Previous research revealed that *Scenedesmus* sp. generate 2.82 l biogas kg TS^{-1} [79] and *Chlamydomonas reinhardtii* 587 ml biogas gr volatile $solids^{-1}$ [80] when the algae are cultivated in wastewater as a nutrient source. In the future, biogas production from microalgae can be added to the existing energy to reduce the consumption of the external energy.

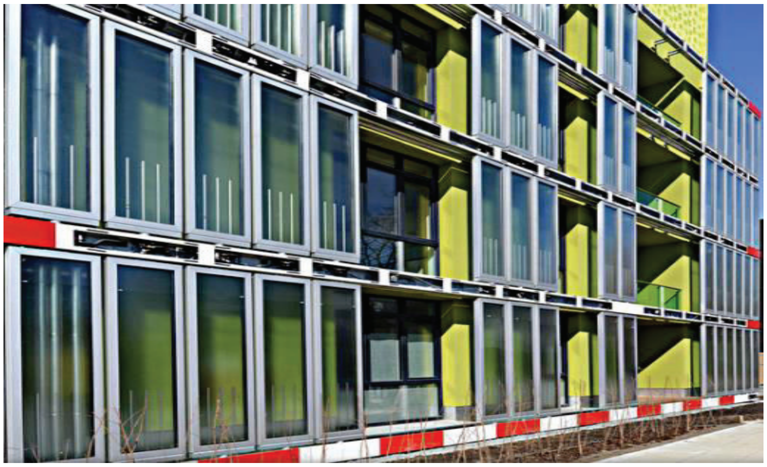
MICROALGAE TECHNOLOGY IN THE GREEN BUILDING

Multifunction of microalgae as phycoremediation and biomass feedstock production offer advantages to the integrating microalgae system into an urban green building. Microalgae can be used to remediate wastewater and to produce clean water couples with CO_2 sequestration and generate O_2 [81]. The microalgae system can be integrated into a green building for architecture purposes in particular of algae in façade design in a closed bioreactor system. This system can be implemented as building components [82]. Thus, the integration of this concept will be the mutual benefits between building requirement for façade components and microalgae cultivation for nutrient recovery from on-site wastewater production [83]. Furthermore, their integration creates a synergism between algal biomass production and urban living for a more sustainable use of urban resources [81].

In regard to microalgae photobioreactor as a building façade, this can be appeared as a promising method to reduce the operating cost for microalgae cultivation technology in forms of light, thermal energy, and nutrient availability while at the same time the microalgae photobioreactor can contribute to the additional benefit of the building for energy reduction and architecture function [82, 83]. The integration of microalgae cultivation in various type of photobioreactor can be seen in the following figures:



A. Integrated of microalgae cultivation in photobioreactor into building façade [83]



B. Solarleaf-building façade in Hamburg, Germany [84]

C. Algae housed [85]

FIGURE 3. Application of the algae technology for building facade

Closed microalgae photobioreactor needs to be designed according to the architecture of the building. The color of the algae will change during the algal growth and become less transparent by increasing of the algal biomass concentration. The liquid façade provide a dynamic appearance which also works as an adaptive sunshade [82]. The integration of microalgae technology into building façade system offers various prosperity for thermal building management for the microalgae photobioreactor and the host building (Fig.3a), and therefore the optimum thermal exchange between the culture and the building is critical to be considered [83]. Furthermore, the integrated algae façade of BIQ house has also built in Hamburg, Germany in 2013 (Fig. 3b). A 200 m^2 of integrated photobioreactor in this building performed as passive-energy from which the algal biomass and heat as renewable energy were generated. This system also provided an effective shading, thermal insulation, and noise abatement. Thus, these promote the benefit of the integrated microalgae system in the sustainable building [84]. Moreover, Figure 3c shows that the algal façade provides the green wall on the outside of the building. In this system, microalgae utilize nutrient from the building wastewater and the sunlight will help microalgae to produce lipid and polyphosphate which can be turned into fuel or bio fertiliser [59, 85].

Although, integration of the algae cultivation in a closed photobioreactor to the building façade is not common worldwide, the potential of its implementation in green building concept is important to be considered in the world of architecture and resource recovery of wastewater from the development of building construction.

CONCLUSION

The microalgae-integrated façade system appears as the potential multiple functions for developing of the future green building. The application of the microalgae system in the building wastewater through phycoremediation will recover the nutrient from the building wastewater, and therefore it eliminates the eutrophication impact in water bodies. The algal biomass can be further treated to produce biomass feedstock for bioenergy, fertiliser, and fine chemicals. At the same time, the algae-façade as a green building component promote an adaptive sunshade and bio-insulation to reduce the external heat. Therefore, to promote the future sustainable building, the algal façade system can be implemented multifunction tasks as bioremediation, biomass production, and an architecture component.

REFERENCES

1. WSP, (2011).
2. A. Suraji, G. W. Surarso, and Y. Supriyatna, presented at the 20th Asia Construct Conference, Hong Kong, (2014) (unpublished).
3. S. O. Ametepey and S. K. Ansah, Journal of Environment and Earth Science **5** (3) (2015).
4. D. Azqueta, Development Policy Review **10** (1992).
5. D. M. Herczeg, D. McKinnon, L. Milios, I. Bakas, E. Klaassens, D. K. Svatikova and O. Widerberg, (2014).
6. A. Darko, C. Zhang, and A. P. C. Chan, Habitat International **60**, 16 (2017).
7. U. Berardi, Sustainable Cities and Society **8**, 9 (2013).
8. A. P. C. Chan, A. Darko and E. E. Ameyaw, Sustainability **9** (969) (2017).
9. A. Darko and A. P. C. Chan, Habitat International **57** (2016).
10. A. Sev, Sustainable Development **17** (2009).
11. H. Son, C. Kim, W. K. Chong and J.-S. Chou, Sustainable Development **19** (337) (2011).
12. J. Lausten, (2008).
13. C. D. Plessis, Construction Management and Economics **25**, 67-76 (2007).
14. H. Falkenbach, A.-L. Lindholm and H. Schleich, Journal of Real Estate Literature: **18** (2) (2010).
15. E. Chan, Q. K. Qian, and PatrickT.I.Lam, Energy Policy **37**, 3061-3070 (2009).
16. S. Bond, Pacific Rim Property Research **16** (3) (2010).
17. N. Murtagh, A. Roberts and R. Hind, Construction Management and Economics **34** (1) (2016).
18. P. H. Shaikha, N. B. M. Norb, A. A. Sahitoa, P. Nallagownden, I. Elamvazuthib and M. S. Shaikhc, Renewable and Sustainable Energy Reviews **75** (2017).
19. Y. H. Ahna, C. W. Jung, M. Suh and M. H. Jeon, Procedia Engineering **145** (2016).
20. H. Rashidi, A. G. Hoseini, A. h. GhaffarianHoseini, N. M. N. Sulaiman, JohnTookey and N. A. Hashim, Renewable and Sustainable Energy Reviews **49** (2015).
21. C.-L. Cheng, J.-J. Peng, M.-C. Ho, W.-J. Liao and S.-J. Chern, Water **236** (2016).
22. S. M. Hocaoglu, Resources, Conservation and Recycling **122**, 43-50 (2017).
23. E. Wanjiru and X. Xia, Sustainable Cities and Society (2017).
24. A. Kalantzis, A. Thatcher and C. Sheridan, Applied Ergonomics, 1-12 (2016).
25. M. Zapater-Pereyra, S. Lavrnic, F. v. Dien, J. J. A. v. Bruggen and P. N. L. Lens, Ecological Engineering **94**, 545-554 (2016).
26. N. Abdel-Raouf, A. A. Al-Homaidan and I. B. M. Ibraheem, Saudi Journal of Biological Sciences **19** (2012).
27. H. M. Campos and M. v. Sperling, Water Science and Technology **34** (3-4) (1996).
28. N. F. Gray, *Biology of Wastewater Treatment*. (Oxford Univ. Press, Oxford, 1998).
29. D. Mara, *Domestic Wastewater Treatment in Developing Countries*. (Earthscan, Sterling, VA. London, 2003).
30. M.-h. Huang, Y.-m. Li and G.-w. Gu, Desalination **262** (2010).
31. A. R. Karimi, N. Mehrdadi, S. J. Hashemian, G. R. N. Bidhendi and R. T. Moghaddam, Int. J. Environ. Sci. Tech. **8** (2) (2011).
32. G. Libralato, A. V. Ghirardini and F. Avezzù, Journal of Environmental Management **94** (2012).
33. M. A. Massoud, A. Tarhini, and J. A. Nasr, Journal of Environmental Management **90**, 8 (2009).
34. ADB, (2012).
35. D. Dwirianti, in *Kitakyushu Initiative for a Clean Environment*, edited by T. Maeda (Institute for Global Environmental Strategies, Kitakyushu, 2009), Vol. (2017).
36. MinistryofHealth, (2010).
37. S. M. Kerstens, M. Spiller, I. Leusbrock and G. Zeemanb, Science of the Total Environment **550**, 14 (2016).
38. J. García, R. Mujeriego, J. M. Obis and J. Bou, Water Policy **3** (4), 341-350 (2001).
39. A. Purnomo and N. Khairina, Procedia - Social and Behavioral Sciences **227**, 791-798 (2016).
40. I. Chirisa, E. Bandauko, A. Matamanda and G. Mandisvika, Applied Water Science **7** (3), 1069-1078 (2017).
41. L. Lijó, S. Malamis, S. González-García, M. T. Moreira, F. Fatone and E. Katsou, Journal of Environmental Management (2016).
42. M. Sartor, M. Kaschek, and V. Mavrov, Desalination **224** (1), 172-177 (2008).
43. J. P. v. d. Hoek, H. d. Fooija and A. Strukera, Resources, Conservation and Recycling **113**, 53-64 (2016).
44. D. J. Batstone, T. Hülsen, C. M. Mehta and J. Keller, Chemosphere **140**, 2-11 (2015).
45. W. Y. Cheah, T. C. Ling, P. L. Show, J. C. Juan, J.-S. Chang and D.-J. Lee, Applied Energy 179 (2016) 609–625 **179** (2016).

46. W. Verstraete, P. Clauwaert, S. E. and Vlaeminck, Bioresource Technology (2016).
47. P. L. McCarty, J. Bae, and J. Kim, Environ. Sci. Technol. **45**, 7100-7106 (2011).
48. UN, (2014).
49. BPS, (2013).
50. S. M. Kerstens, A. Priyanka, K. C. v. Dijk, F. J. D. Ruijter, I. Leusbrocke and G. Zeemane, Resources, Conservation and Recycling **110**, 16-29 (2016).
51. W. Verstraete, P. Van de Caveye, and V. Diamantis, Bioresource Technology **100** (23), 5537-5545 (2009).
52. D. Puyol, D. J. Batstone, T. Hülsen, S. Astals, M. Peces and J. O. Krömer, Frontiers in Microbiology **7** (2106) (2017).
53. Y. Shen, J. L. Linville, M. Urgun-Demirtas, M. M. Mintz and S. W. Snyder, Renewable and Sustainable Energy Reviews **50**, 346-362 (2015).
54. J. M. Prandini, M. L. B. da Silva, M. P. Mezzari, M. Pirolli, W. Michelon and H. M. Soares, Bioresource Technology **202**, 67-75 (2016).
55. N. A. Cano Londoño, D. G. Suárez, H. I. Velásquez and G. J. Ruiz-Mercado, Journal of Cleaner Production **141**, 182-193 (2017).
56. I. Rawat, R. R. Kumar, T. Mutanda and F. Bux, Applied Energy **88**, 3411-3424 (2011).
57. L. Wang, M. Min, Y. Li, P. Chen, Y. Chen, Y. Liu, Y. Wang and R. Ruan, Appl Biochem Biotechnol **162**, 1174-1186 (2010).
58. Q.-x. Kong, L. Li, B. Martinez, P. Chen and R. Ruan, Appl Biochem Biotechnol **160**, 9-18 (2010).
59. A. Yulistyorini, Doctoral Degree, University of Leeds, (2016).
60. L. E. González, R. O. Cañizares, and S. Baena, Bioresource Technology **60** (3), 259-262 (1997).
61. W. Zhou, Y. Li, M. Min, B. Hu, H. Zhang, X. Ma, L. Li, Y. Cheng, P. Chen and R. Ruan, Applied Energy **98**, 433-440 (2012).
62. A. Ruiz-Marin, L. G. Mendoza-Espinosa and T. Stephenson, Bioresource Technology **101** (1), 58-64 (2010).
63. L. Pilon, H. Berberoglu and R. Kandilian, Journal of Quantitative Spectroscopy & Radiative Transfer **112**, 2639-2660 (2011).
64. J. A. Posada, L. B. Brentner, A. Ramirez and M. K. Patel, Algal Research **17**, 113-131 (2016).
65. P. Spolaore, C. Joannis-Cassan, E. Duran and A. Isambert, Journal of Bioscience And Bioengineering **101** (2), 87-96 (2006).
66. S. Abinandan and S.Shanthakumar, Renewable and Sustainable Energy Reviews **52**, 123-132 (2015).
67. L. Brennan and P. Owende, Renewable and Sustainable Energy Reviews **14**, 557-577 (2010).
68. R. Slade and A. Bauen, Biomass and Bioenergy **53**, 29-38 (2013).
69. J. Singh and S. Gu, Renewable and Sustainable Energy Reviews **14**, 2596-2610 (2010).
70. 70. P. M. Schenk, S. R. Thomas-Hall, E. Stephens, U. C. Marx, J. H. Mussgnug, C. Posten and O. K. B. Hankamer, Bioenerg. Res. **1**, 20-43 (2008).
71. Y. Chisti, Biotechnology Advances **25**, 294-306 (2007).
72. Q. Hu, M. Sommerfeld, E. Jarvis, M. Ghirardi, M. Posewitz, M. Seibert and A. Darzins, The Plant Journal **54**, 621-639 (2008).
73. J. K. Pittman, A. P. Dean and O. Osundeko, Bioresource Technology **102**, 17-25 (2011).
74. L. E. de-Bashan and Y. Bashan, Bioresource Technology **101**, 1611-1627 (2010).
75. S. Krishnamoorthy, M. Premalatha and M. Vijayasekaran, Journal of Cleaner Production **148**, 735-750 (2017).
76. E. J. Olguı´n, Biotechnology Advances **22**, 81-91 (2003).
77. M. E. Martinez, S. Sanchez, J. M. Jimenez, F. E. Yous and L. Munoz, Bioresource Technology **73**, 263-272 (2000).
78. L. Wang, Y. Li, P. Chen, M. Min, Y. Chen, J. Zhu and R. R. Ruan, Bioresource Technology **101** (8), 2623-2628 (2010).
79. C. Ledda, A. Schievano, B. Scaglia, M. Rossoni, F. G. Acién Fernández and F. Adani, Journal of Cleaner Production **112**, 103-112 (2016).
80. E. Menger-Krug, J. Niederste-Hollenberg, T. Hillenbrand and H. Hiessl, Environ. Sci. Technol. **46** (21), 11505-11514 (2012).
81. G. Proksch, Edinburgh Architectural Research Journal **33** (2013).
82. F. Qiu, *Algae Architecture*. (TU Delft, Delft, The Netherland, 2013).
83. J. Pruvost, B. L. Gouic, O. Lepine, J. Legrand and F. L. Borgne, Chemical Engineering Journal **284**, 850-861 (2016).
84. Colt, (Colt International, Arup Deutschland, SSC GmbH, Hamburg, Germany, 2013), Vol. (2017).
85. M. Bernard, (Buildipedia, 2011), Vol. (2017).