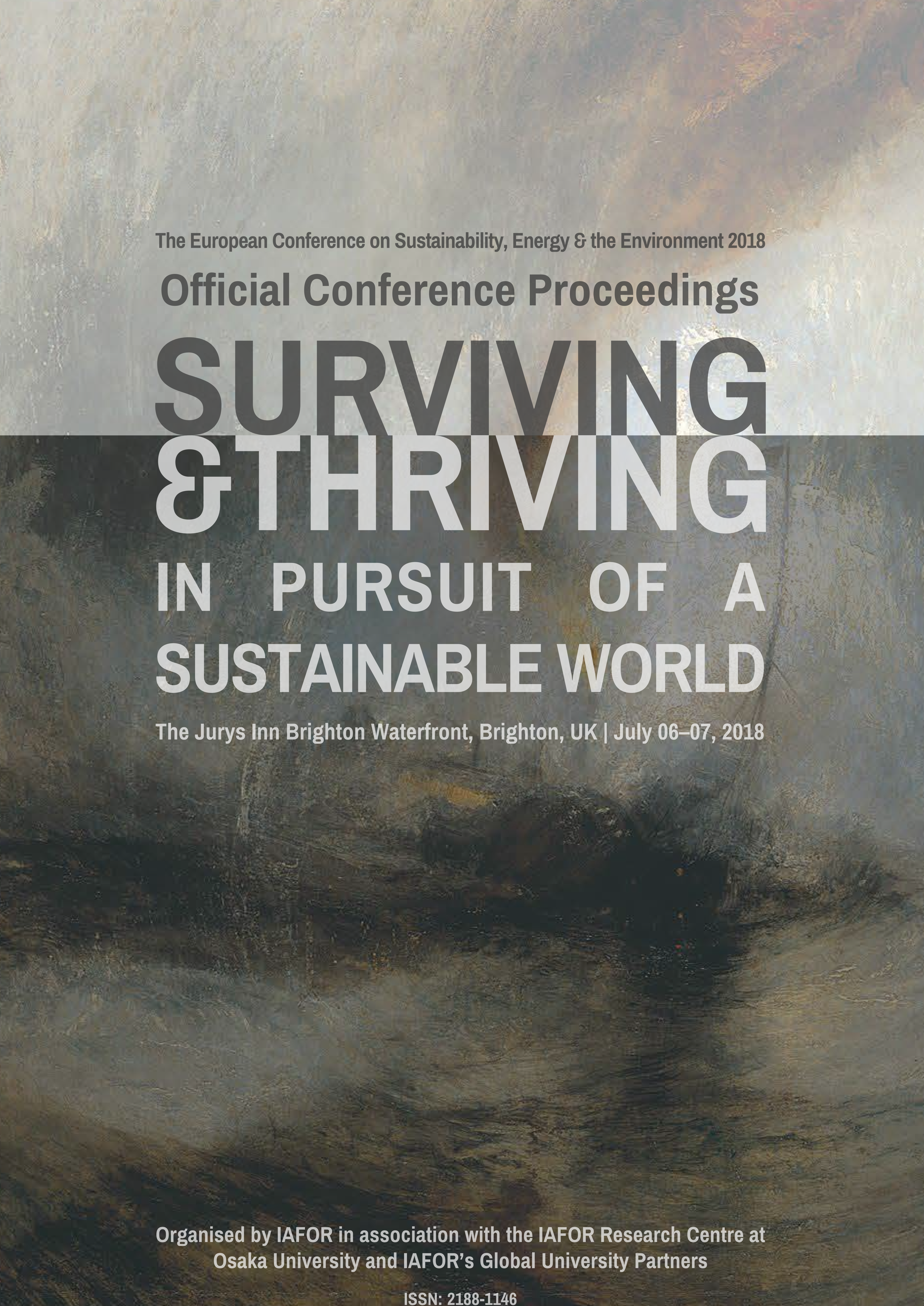

The European Conference on Sustainability, Energy & the Environment 2018

Official Conference Proceedings

SURVIVING & THRIVING IN PURSUIT OF A SUSTAINABLE WORLD

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Very Short-Term Electrical Energy Consumption Forecasting of a Household for the Integration of Smart Grids

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Abstract
The recent integration of smart grid systems to present electric power systems and the increasing penetration of renewable energy sources make electrical energy consumption forecasting not only a prominent subject but also an arduous challenge due to nonlinear and nonstationary characteristics of electric loads which can be affected by seasonal effects, weather conditions, socioeconomic dynamics, and random effects. Very short-term electrical energy consumption forecasting (VSTCF), which includes few minutes to an hour ahead forecasting of electrical energy consumption, ensures monitoring energy consumption, identifying base and peak loads, making feasible decisions for renewable energy investments such as photovoltaic (PV) systems, and improving energy management quality of a household for the smart grid integration. In this paper, for the first time in Turkey, electrical energy consumption data of a household with an averaging period of 10-minute is obtained by an energy logger during a 1-month period in order to perform VSTCF by using several artificial intelligence (AI) techniques including decision trees (DT), genetic algorithm (GA), artificial neural networks (ANN), and support vector machines (SVM) in the literature. After data pre-processing, various AI techniques will be applied to real-time data obtained from a household in the Mediterranean Region of Turkey for the calculation of mean absolute error (MAE) performance metric. Results indicate that gradient boosted decision trees (GBDT) have the best performance in comparison with other techniques for VSTCF.

Keywords: Very-short term, energy forecasting, household, smart grid integration, artificial intelligence, decision trees, genetic algorithm, artificial neural networks, support vector machines, mean absolute error.

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Introduction

After the deregulation of electric power system, distributed generation of electricity has become more important due to onsite generation and efficient use of electrical energy in a small environment. Increasing share of renewable energy technologies among today's power plants and current integration of smart grid systems to modern day's electric power systems not only make energy forecasting a popular subject in energetics, but also categorise it as a demanding challenge with highly unpredictability because of the influencing factors such as social activities, climate and seasonal factors.

According to time period, energy forecasting can be classified as shown in Figure 1. VSTCF (or ultra-short term electrical energy consumption forecasting) includes between 1-minute and 1-hour ahead forecasts, while short-term electrical energy consumption forecasting (STCF) contains among 1-hour and 2 weeks ahead forecasts. Medium-term (or mid-term) electrical energy consumption forecasting (MTCF) refers to future predictions from 2 weeks to 3 years and long-term electrical energy consumption forecasting (LTCF) is performed for forecasts from 3 years up to 50 years (Zor et al., 2017b).

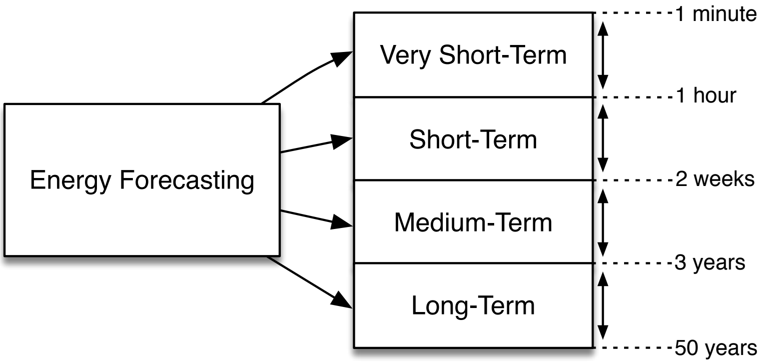


Figure 1: Energy forecasting classification according to time period.

Although several techniques have been developed for use in STCF, the existing literature related to VSTCF is notably numbered. In the literature, VSTCF is commonly employed for smart grid and automated demand response applications. Perpetual developments in advanced metering infrastructure (AMI) system and smart meter provide obtaining electrical energy consumption data from individual households instantly by initialising bi-directional communication between electricity distribution companies and individual households. This results in accelerating personalised auto demand response applications in individual households, which leads to customised contracts and rates, such as a dynamic rate and bi-directional transaction bidding, and causes effective deployment of electricity (Hsiao, 2015).

In this paper, electrical energy consumption data of a household with an averaging period of 10-minute is obtained for the first time in Turkey by an energy logger during a 1-month period in order to perform VSTCF by employing various AI techniques including DT, GA, ANN, and SVM. After the introduction section, the recent literature, material and methods containing household properties, data acquisition, and data set information, evaluation criterion, discussion and results, and conclusions are explained respectively.

Literature Review

At the beginning of the VSTCF literature, Liu et al. made a comparison of VSTCF techniques named as fuzzy logic (FL), neural networks (NN), and auto-regressive model (AR) for an automatic generation control (AGC) system in a multi-area interconnected power system to match area generation to area load, to regulate system frequency and area net interchange to their scheduled values, and to distribute area generation economically among available resources (Liu et al., 1996). Feng et al. proposed a method for VSTCF based on ANN in order to address problems and solutions related to forecasting in a lead time of 10 minutes (Feng et al., 1997).

Charytoniuk and Chen presented a novel approach that leads to a better accuracy for VSTCF by the application ANN to model load dynamics (Charytoniuk and Chen, 2000). Shamsollahi et al. developed and implemented an ANN based VSTCF model for the interim electricity market of ISO New England (Shamsollahi et al., 2001). Chen et al. reported upon the implementation and performance analysis of VSTCF in electronic dispatch project in ISO-NE (Chen et al., 2001). Trudnowski et al. described a strategy for developing a very short-term load predictor using slow and fast Kalman estimators (Trudnowski et al., 2001). In 2006, Yang et al. presented an improved fuzzy neural system (FNS) for electric VSTCF problem based on chaotic dynamics reconstruction technique (Yang et al., 2006). James W. Taylor used minute-by-minute British electricity demand observations to evaluate methods for prediction between 10 and 30 minutes ahead (Taylor, 2008). Setiawan et al. performed a new approach for VSTCF by applying support vector regression to predict the load demand every five minutes based on historical data from the Australian electricity operator NEMMCO from 2006 to 2008 (Setiawan et al., 2009). De Andrade and Da Silva tried to achieve a comparative analysis among autoregressive integrated moving average (ARIMA) model, ANN and adaptive neuro-fuzzy inference system (ANFIS) techniques for load demand forecasting in distributed substations of cities located in Sao Paulo state of Brazil (De Andrade and Da Silva, 2009). Guan et al. presented a methodology based on multilevel wavelet neural networks with novel pre-filtering in order to detect and eliminate spikes within load, apply the wavelet technique to decompose the load into several frequency components, perform appropriate transformation on each component, and feed it together with other appropriate input to a separate neural network (Guan et al., 2009).

Koprinska et al. used autocorrelation analysis to extract 6 nested feature sets of previous electricity loads for 5 minute ahead electricity load forecasting (Koprinska et al., 2010). Qingle and Min proposed a novel approach to very short-term load by the application of ANN and rough set (Qingle and Min, 2010). Guan et al. presented a method of multilevel wavelet neural networks trained by hybrid Kalman algorithms (MWNNHK) to forecast next hour’s load in five-minute steps and generate a moving prediction every five minutes, around which a good confidence interval (CI) is estimated at the same time (Guan et al., 2010). Cheah et al. used a quarter-hourly ahead load forecasting model employing a multilayer neural network with a backpropagation learning algorithm in NI LabVIEW (Cheah et al., 2011). Kotillova performed 30-minute Australian electricity demand observations to evaluate time series forecasting methods for prediction 30 minutes ahead (Kotillova, 2011). Neusser et al. employed VSTCF for a complete real-time distributed demand side management system in absence of historical data (Neusser et al., 2012). Shankar et al. used Kalman filter prediction recursive algorithms to obtain a bank of hourly predicted load data for 5-minute look ahead forecasting (Shankar et al., 2012). An et al. proposed a method of first treating the data by scale through wavelet analysis and then selecting partially similar day to forecast various loads in different frequencies with more load forecast models for VSTCF under the influence of electric railway (An et al., 2013). Shang presented a number of functional modelling and forecasting methods for predicting very short-term (such as minute-by-minute) electricity demand. The suggested functional methods slice a seasonal univariate time series (TS) into a TS of curves; reduce the dimensionality of curves by applying functional principal component analysis (PCA) before using a univariate TS forecasting method and regression techniques (Shang, 2013). Khan et al. applied a neuro-evolutionary technique known as Cartesian genetic programming evolved recurrent neural network to develop a load forecasting model for very short-term of half an hour (Khan et al., 2013).

Hsiao performed a novel approach to model the load of an individual household based on context information and its daily schedule in Taiwan with a VSTCF horizon of 30 minutes (Hsiao, 2015). Golestaneh et al. proposed a nonparametric approach to generate very short-term predictive densities, i.e., for lead times between a few minutes to one hour ahead, with fast frequency updates especially by relying on an extreme learning machine (ELM) as a fast regression model (Golestaneh et al., 2016). Yoon et al. suggested a VSTCF method based on pattern ratio for an office building in Korea (Yoon et al., 2016). Barbieri et al. presented an overview of the various tools needed to forecast photovoltaic (PV) power within a very short-term horizon (Barbieri et al., 2017). Sepasi et al. employed two parallel-series techniques for load forecasting to optimize the performance of a grid-scale battery energy storage system (BESS) (1 MW, 1.1 kWh) in 15-minute steps within a moving 24-hour window (Sepasi et al., 2017). Lastly, Capuno et al. presented a model for VSTCF based on algebraic prediction (AP) using a modified concept of the Hankel rank of a sequence. Moreover, AP is coupled with support vector regression (SVR) to accommodate weather forecast parameters for improved accuracy of a longer prediction horizon; thus, a hybrid model was also proposed (Capuno et al., 2017).

Material and Methods

The household is located on the second floor in an apartment which is settled in Mahfesığmaz neighbourhood in Çukurova district, Adana, Turkey. Geographical properties of the household are given in Table 1 and household location is shown in Figure 2.

Table 1: Geographical properties of the household

Household Location	Latitude	Longitude	Altitude
Mahfesığmaz, Çukurova	37.042 N	35.314 E	81 m

VSTCF of a household is an arduous challenge because of the fact that electric loads are characterised as nonlinear, and electrical appliances in the household vary due to their operation. For instance, a refrigerator has continuous operation, while a television (TV) and a TV console operate in standby generally. There are also other appliances such as a washing machine, a dishwasher, or a vacuum cleaner which have operation on demand.

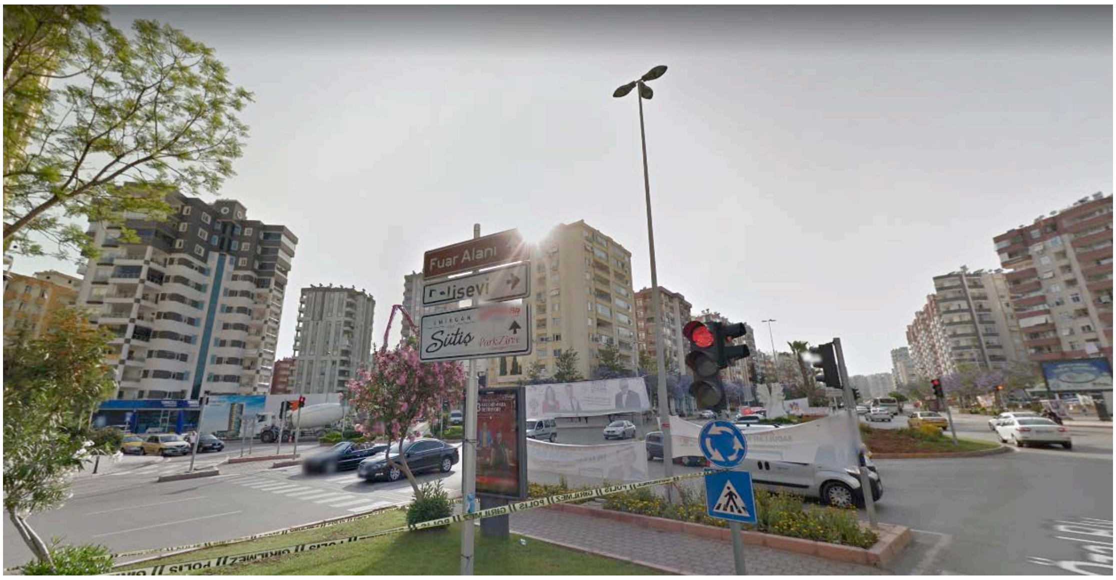


Figure 2: Household location (GoogleMaps, 2015).

Data acquisition stage of electrical energy consumption is performed between May 11 and June 8, 2018 by an energy logger through the distribution panel indicated in Figure 3. Obtained electrical energy consumption data is demonstrated in Figure 4.

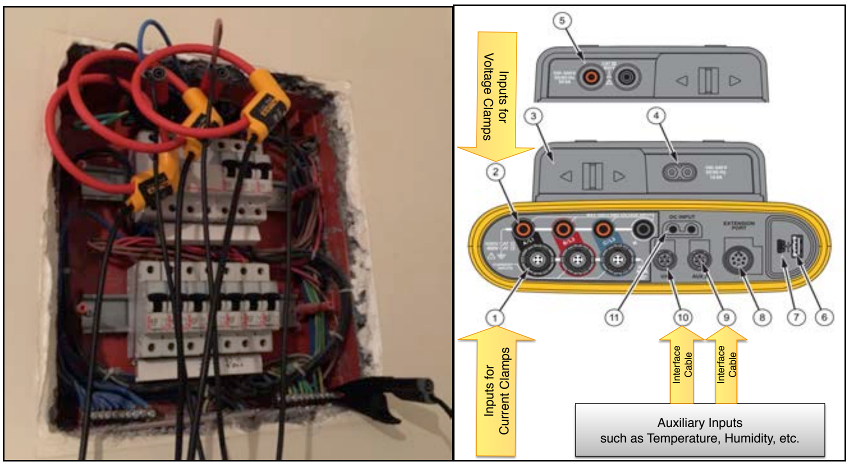


Figure 3: Distribution panel and energy logger connection schematic (Fluke, 2013).

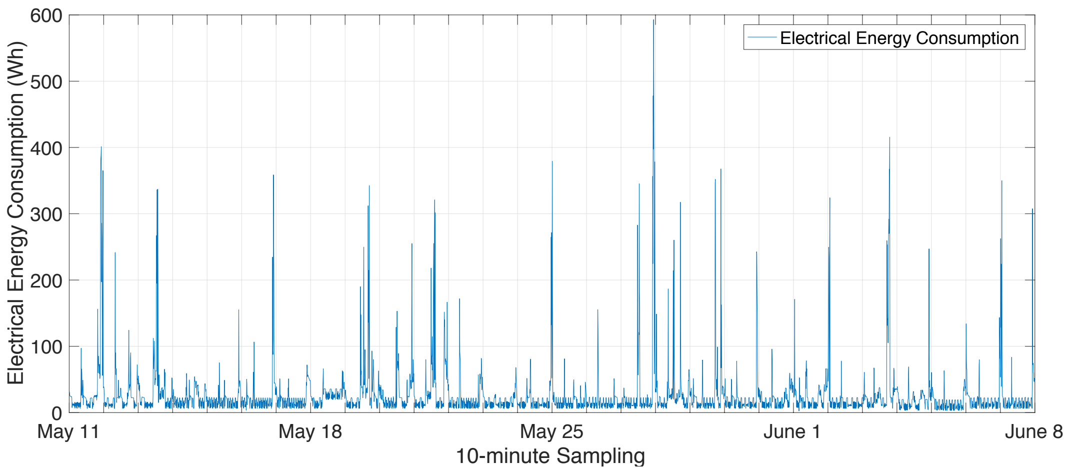


Figure 4: Electrical energy consumption data.

For weather data, MERRA-2 which stands for Modern-Era Retrospective Analysis for Research and Applications – Version 2 data (GMAO, 2015) is utilised. MERRA-2 presents a time series of temperature, relative humidity, pressure, wind speed and direction, rainfall, snowfall, and snow depth with time steps ranging from 1-minute up to 1-month (Gelaro et al., 2017). MERRA-2 data are illustrated in the following figures.

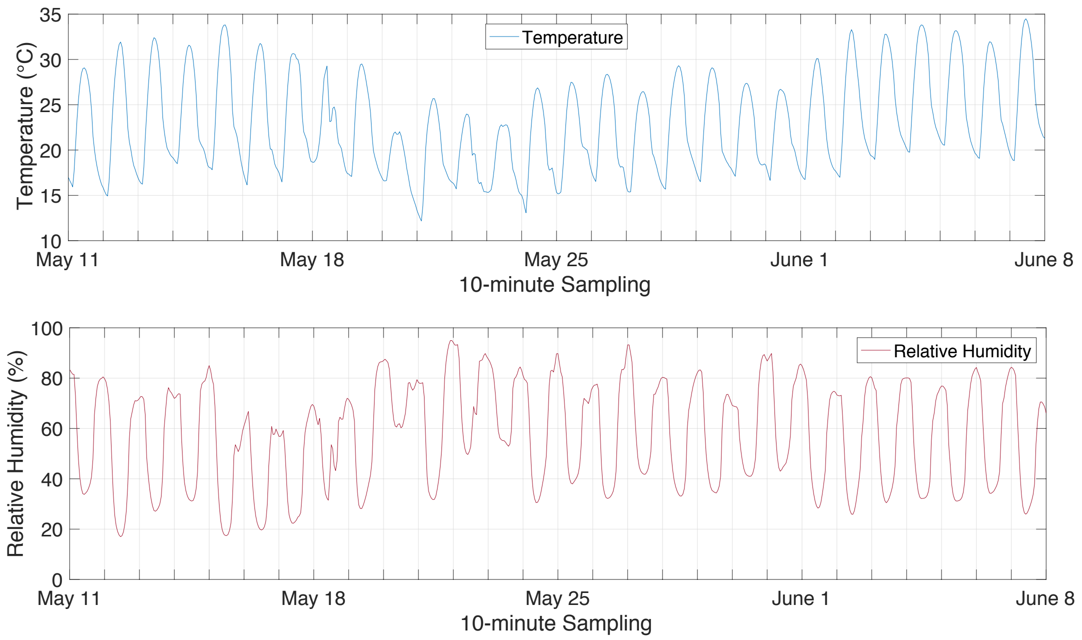


Figure 5: Temperature and relative humidity data.

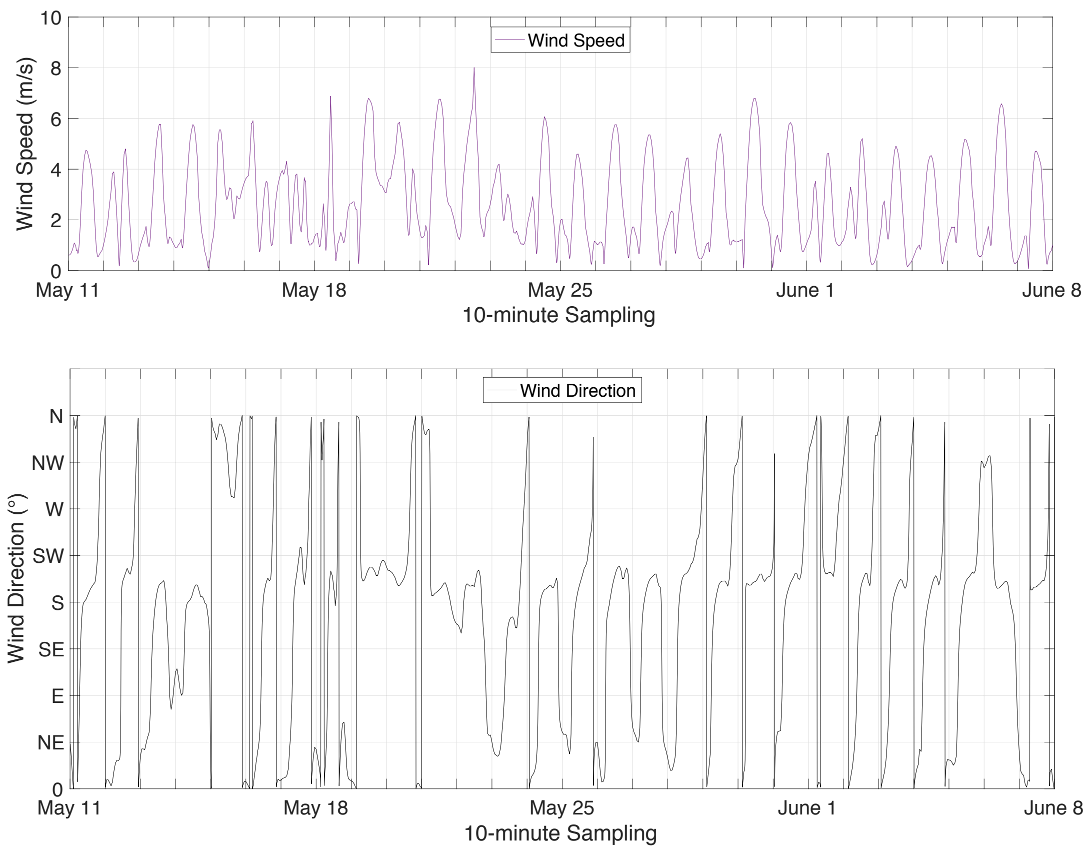


Figure 6: Wind speed and direction data.

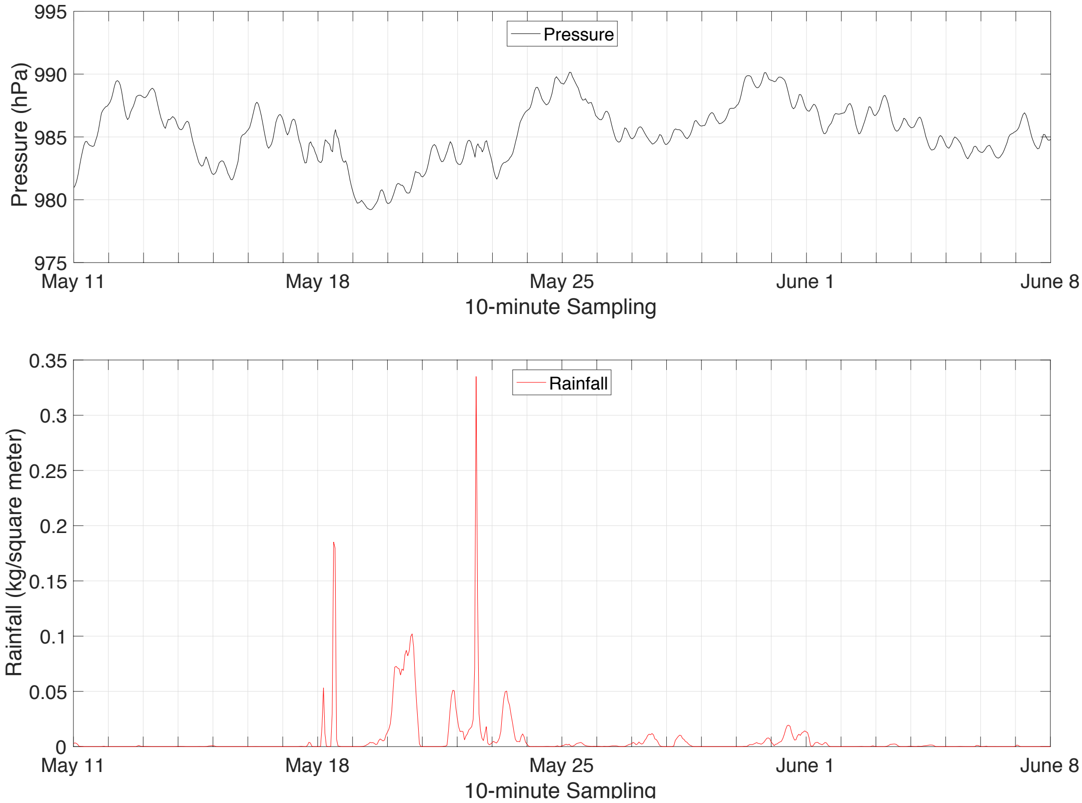


Figure 7: Pressure and rainfall data.

Data set consists of three type of input variables which are electrical, calendar, and weather inputs. Electrical variables are previous day (PrevD), previous hour (PrevH), and previous 10-minute (PrevS). Calendar inputs are day of week (DoW), hour of day (HoD), and sample of hour (SoH). Weather variables are temperature (Temp), relative humidity (RH), wind speed (WindS), wind direction (WindD), pressure (Pres), and rainfall (Rain). The data set is constituted of 4,032 rows and 13 columns (12 input and 1 target). Demonstration of system inputs and target is given in Figure 8. View of the data set in MATLAB environment is shown in Figure 9 (MATLAB, 2017).

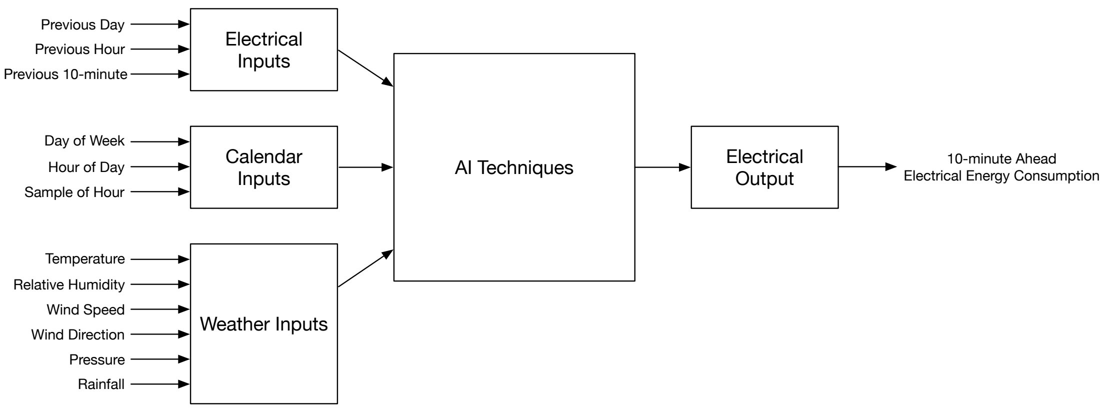
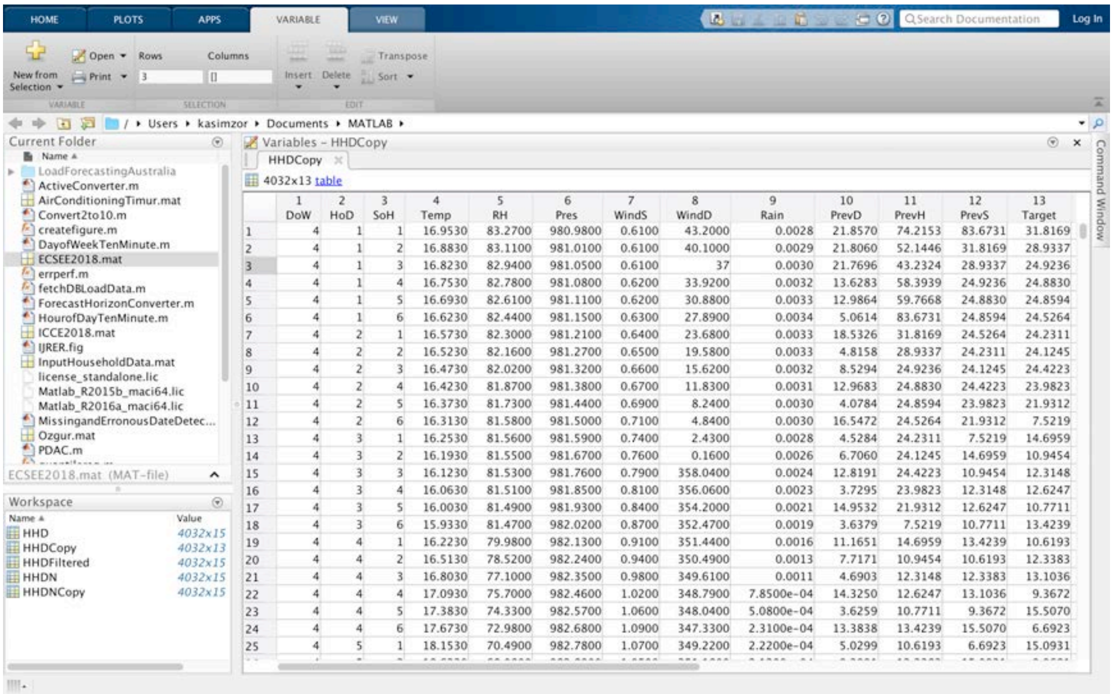


Figure 8: Illustration of system inputs and target.



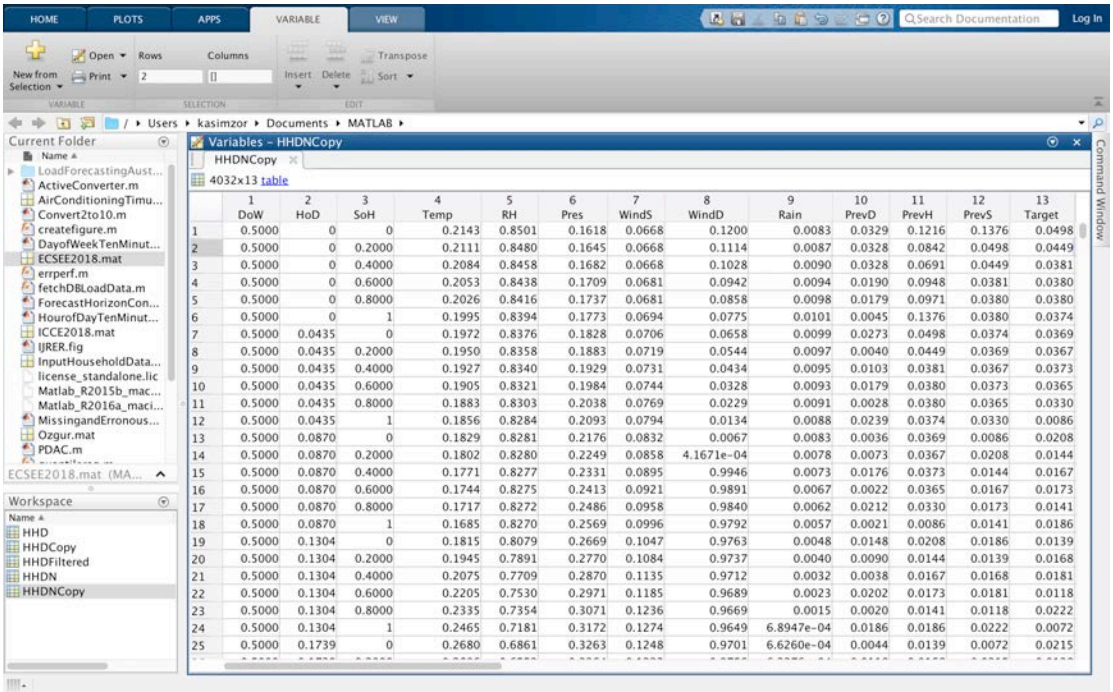
Variables - HHDCopy — 4032x13 table

	1 DoW	2 HoD	3 SoH	4 Temp	5 RH	6 Pres	7 WindS	8 WindD	9 Rain	10 PrevD	11 PrevH	12 PrevS	13 Target
1	4	1	1	16.9530	83.2700	980.9800	0.6100	43.2000	0.0028	21.8570	74.2153	83.6731	31.8169
2	4	1	2	16.8830	83.1100	981.0100	0.6100	40.1000	0.0029	21.8060	52.1446	31.8169	28.9337
3	4	1	3	16.8230	82.9400	981.0500	0.6100	37	0.0030	21.7696	43.2324	28.9337	24.9236
4	4	1	4	16.7530	82.7800	981.0800	0.6200	33.9200	0.0032	13.6283	58.3939	24.9236	24.8830
5	4	1	5	16.6930	82.6100	981.1100	0.6200	30.8800	0.0033	12.9864	59.7668	24.8830	24.8594
6	4	1	6	16.6230	82.4400	981.1500	0.6300	27.8900	0.0034	5.0614	83.6731	24.8594	24.5264
7	4	2	1	16.5730	82.3000	981.2100	0.6400	23.6800	0.0033	18.5326	31.8169	24.5264	24.2311
8	4	2	2	16.5230	82.1600	981.2700	0.6500	19.5800	0.0033	4.8158	28.9337	24.2311	24.1245
9	4	2	3	16.4730	82.0200	981.3200	0.6600	15.6200	0.0032	8.5294	24.9236	24.1245	24.4223
10	4	2	4	16.4230	81.8700	981.3800	0.6700	11.8300	0.0031	12.9683	24.8830	24.4223	23.9823
11	4	2	5	16.3730	81.7300	981.4400	0.6900	8.2400	0.0030	4.0784	24.8594	23.9823	21.9312
12	4	2	6	16.3130	81.5800	981.5000	0.7100	4.8400	0.0030	16.5472	24.5264	21.9312	7.5219
13	4	3	1	16.2530	81.5600	981.5900	0.7400	2.4300	0.0028	4.5284	24.2311	7.5219	14.6959
14	4	3	2	16.1930	81.5500	981.6700	0.7600	0.1600	0.0026	6.7060	24.1245	14.6959	10.9454
15	4	3	3	16.1230	81.5300	981.7600	0.7900	358.0400	0.0024	12.8191	24.4223	10.9454	12.3148
16	4	3	4	16.0630	81.5100	981.8500	0.8100	356.0600	0.0023	3.7295	23.9823	12.3148	12.6247
17	4	3	5	16.0030	81.4900	981.9300	0.8400	354.2000	0.0021	14.9532	21.9312	12.6247	10.7711
18	4	3	6	15.9330	81.4700	982.0200	0.8700	352.4700	0.0019	3.6379	7.5219	10.7711	13.4239
19	4	4	1	16.2230	79.9800	982.1300	0.9100	351.4400	0.0016	11.1651	14.6959	13.4239	10.6193
20	4	4	2	16.5130	78.5200	982.2400	0.9400	350.4900	0.0013	7.7171	10.9454	10.6193	12.3383
21	4	4	3	16.8030	77.1000	982.3500	0.9800	349.6100	0.0011	4.6903	12.3148	12.3383	13.1036
22	4	4	4	17.0930	75.7000	982.4600	1.0200	348.7900	7.8500e-04	14.3250	12.6247	13.1036	9.3672
23	4	4	5	17.3830	74.3300	982.5700	1.0600	348.0400	5.0800e-04	3.6259	10.7711	9.3672	15.5070
24	4	4	6	17.6730	72.9800	982.6800	1.0900	347.3300	2.3100e-04	13.3838	13.4239	15.5070	6.6923
25	4	5	1	18.1530	70.4900	982.7800	1.0700	349.2200	2.2200e-04	5.0299	10.6193	6.6923	15.0931

Figure 9: Data set.

Normalisation process is generally employed to eliminate the units of different data types in the data set and compare performances of diversified data columns as well. In order to reach a data distribution between 0 and 1 for each column, the following formula can be applied for $y_{min} = 0$ and $y_{max} = 1$

$$x_{norm} = (y_{max} - y_{min}) \times \left[\frac{x - x_{min}}{x_{max} - x_{min}} \right] + y_{min} \qquad (1)$$



Variables - HHDNCopy — 4032x13 table

	1 DoW	2 HoD	3 SoH	4 Temp	5 RH	6 Pres	7 WindS	8 WindD	9 Rain	10 PrevD	11 PrevH	12 PrevS	13 Target
1	0.5000	0	0	0.2143	0.8501	0.1618	0.0668	0.1200	0.0083	0.0329	0.1216	0.1376	0.0498
2	0.5000	0	0.2000	0.2111	0.8480	0.1645	0.0668	0.1114	0.0087	0.0328	0.0842	0.0498	0.0449
3	0.5000	0	0.4000	0.2084	0.8458	0.1682	0.0668	0.1028	0.0090	0.0328	0.0691	0.0449	0.0381
4	0.5000	0	0.6000	0.2053	0.8438	0.1709	0.0681	0.0942	0.0094	0.0190	0.0948	0.0381	0.0380
5	0.5000	0	0.8000	0.2026	0.8416	0.1737	0.0681	0.0858	0.0098	0.0179	0.0971	0.0380	0.0380
6	0.5000	0	1	0.1995	0.8394	0.1773	0.0694	0.0775	0.0101	0.0045	0.1376	0.0380	0.0374
7	0.5000	0.0435	0	0.1972	0.8376	0.1828	0.0706	0.0658	0.0099	0.0273	0.0498	0.0374	0.0369
8	0.5000	0.0435	0.2000	0.1950	0.8358	0.1883	0.0719	0.0544	0.0097	0.0040	0.0449	0.0369	0.0367
9	0.5000	0.0435	0.4000	0.1927	0.8340	0.1929	0.0731	0.0434	0.0095	0.0103	0.0381	0.0367	0.0373
10	0.5000	0.0435	0.6000	0.1905	0.8321	0.1984	0.0744	0.0328	0.0093	0.0179	0.0380	0.0373	0.0365
11	0.5000	0.0435	0.8000	0.1883	0.8303	0.2038	0.0769	0.0229	0.0091	0.0028	0.0380	0.0365	0.0330
12	0.5000	0.0435	1	0.1856	0.8284	0.2093	0.0794	0.0134	0.0088	0.0239	0.0374	0.0330	0.0086
13	0.5000	0.0870	0	0.1829	0.8281	0.2176	0.0832	0.0067	0.0083	0.0036	0.0369	0.0086	0.0208
14	0.5000	0.0870	0.2000	0.1802	0.8280	0.2249	0.0858	4.1671e-04	0.0078	0.0073	0.0367	0.0208	0.0144
15	0.5000	0.0870	0.4000	0.1771	0.8277	0.2331	0.0895	0.9946	0.0073	0.0176	0.0373	0.0144	0.0167
16	0.5000	0.0870	0.6000	0.1744	0.8275	0.2413	0.0921	0.9891	0.0067	0.0022	0.0365	0.0167	0.0173
17	0.5000	0.0870	0.8000	0.1717	0.8272	0.2486	0.0958	0.9840	0.0062	0.0212	0.0330	0.0173	0.0141
18	0.5000	0.0870	1	0.1685	0.8270	0.2569	0.0996	0.9792	0.0057	0.0021	0.0086	0.0141	0.0186
19	0.5000	0.1304	0	0.1815	0.8079	0.2669	0.1047	0.9763	0.0048	0.0148	0.0208	0.0186	0.0139
20	0.5000	0.1304	0.2000	0.1945	0.7891	0.2770	0.1084	0.9737	0.0040	0.0090	0.0144	0.0139	0.0168
21	0.5000	0.1304	0.4000	0.2075	0.7709	0.2870	0.1135	0.9712	0.0032	0.0038	0.0167	0.0168	0.0181
22	0.5000	0.1304	0.6000	0.2205	0.7530	0.2971	0.1185	0.9689	0.0023	0.0202	0.0173	0.0181	0.0118
23	0.5000	0.1304	0.8000	0.2335	0.7354	0.3071	0.1236	0.9669	0.0015	0.0020	0.0141	0.0118	0.0222
24	0.5000	0.1304	1	0.2465	0.7181	0.3172	0.1274	0.9649	6.8947e-04	0.0186	0.0186	0.0222	0.0072
25	0.5000	0.1739	0	0.2680	0.6861	0.3263	0.1248	0.9701	6.6260e-04	0.0044	0.0139	0.0072	0.0215

Figure 10: Normalised data set.

where x is an input vector, x_{min} and x_{max} represent minimum and maximum values of the x, y_{min} and y_{max} correspond to boundaries for distribution, and x_{norm} is the normalised version of the vector x (Çelik and Teke, 2017). Normalised data set is illustrated in Figure 10.

In the scope of this paper, DT, GA, ANN, and SVM are employed as AI techniques. Firstly, GBDT technique in DT literature is used for the forecasting process. Huber's quantile cut-off is performed as a loss function which is a hybrid of ordinary least squares (OLS) and least absolute deviation (LAD). For GBDT, number of maximum trees is 400, maximum splitting levels is 5, variable weights are chosen as equal, minimum size node to split is 10. In GBDT, random sampling is utilised for tree validation and tree pruning criterion is selected as MAE.

Secondly, gene expression programming (GEP) technique which performs a genotype/phenotype GA is employed for the prediction of VSTCF of the household. GEP is linear, ramified, and faster than old GAs and applies symbolic regression. 10-fold cross validation (CV) is chosen for the validation.

Thirdly, multilayer perceptron (MLP) neural networks, radial basis function (RBF) networks, generalised regression neural networks (GRNN), and grouping method of data handling (GMDH) type neural networks are investigated as ANN techniques. For MLP neural networks, a topology with 1 hidden layer is used and a search is conducted to find the optimal size of the hidden layer from 2 to 25 neurons. Logistic sigmoid and linear activation functions are utilised for the hidden and output layer respectively. For RBF networks, Gaussian function is used. Minimum and maximum values of r and λ are 0.01 and 573.301, and 0.012 and 9.984 sequentially. Regularisation λ for final weights is $1\times e^{-10}$ after 4 iterations. For GRNN, 4 layers are constituted as input, hidden (kernel), pattern, and decision layer. Gaussian function is employed as a kernel function for the hidden layer. 2 neurons are utilised on the topology for denominator and numerator summation units. Conjugate gradient algorithm is selected for the optimisation of σ values. For GMDH type neural networks, a topology consisting of independent variables, GMDH network, and dependent variables are built. Number of neurons per layer is fixed to 20 and quadratic polynomial with two variables is used. For all ANN techniques, 10-fold CV is selected for the validation.

Lastly, ε-Support vector regression (ε-SVR) is performed for SVM technique. Gaussian RBF type kernel function is used for ε-SVR. Grid and pattern search for optimal values is applied and the search criterion is minimising total error. ε, C, γ, and P parameter values belonging to ε-SVR are 0.001, 1521.702, 0122, and 0.484 respectively. Number of support vectors used for the prediction is 3,797. 10-fold CV is chosen for the validation of ε-SVR.

Evaluation Criterion

MAE is frequently used for evaluating point load forecasts (Xie and Hong, 2017), it calculates the average absolute forecast error of n times forecast results

$$\mathrm{MAE} = \sum_{i=1}^{n} \frac{|y_i - \hat{y}_i|}{n} \quad (2)$$

where y_i represents actual or measured output, $\hat{y}_i$ shows predicted output and n indicates the number of observations (Zor et al., 2017a).

Discussion and Results

For both training and validation, MAE performance metric results according to the performed analyses in order to apply VSTCF for the household are demonstrated in Table 2.

Table 2: MAE performance metric results

Performed Technique	Model	MAE (Wh) Training	MAE (Wh) Validation
Decision Trees	GBDT	9.38*2nd	10.56*1st
Genetic Algorithm	GEP	12.28	12.51
Artificial Neural Networks	MLP	12.68	13.44
	RBF	11.21	14.25
	GRNN	8.62*1st	12.27*3rd
	GMDH	12.05	12.90
Support Vector Machines	ε-SVR	11.27*4th	11.72*2nd
	Average	11.07	12.52

As stated in Table 2, GBDT model has the best performance for household VSTCF problem. It is also considered that GRNN and ε-SVR models accomplished better estimation in comparison with GEP, MLP, RBF, and GMDH models as well.

Conclusions

In this paper, VSTCF for smart grid integration of households is investigated. Data acquisition period occupies an interval between May 11 and June 8, 2018. For electrical data acquisition a three-phase energy logger is used as a data acquisition terminal of the household. Weather data are obtained from MERRA-2.

The data set contains 4,032 samples with 12 inputs and 1 target. Normalisation of data is realised. Several AI techniques including DT, GA, ANN, and SVM are implemented and achieved results are evaluated according to MAE performance metric as an evaluation criterion.

Consequently, results show that GBDT illustrated an excellent performance in applying VSTCF for the household while GRNN and ε-SVR performed good and reasonable performances respectively.

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Nanocellulose: Types, Sythesis and Applications

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Abstract
Based on the current level of ecological awareness, it is difficult to ignore hazardous emissions from any industrial process or human activities because of its adverse impacts on the environment. The substitution of input materials with less- or non-toxic, eco-friendly or renewable raw materials, where possible, has been the concern of various researchers in recent times. Nanocellulose, a subset of nanomaterials obtained from cellulose which is one of the most abundant natural resources globally, has the potential to provide a sustainable, renewable and environmentally benign building blocks, with improved characteristics for diverse applications in the nanotechnology community for the benefit of mankind. In this paper, the three main categories of nanocellulose and synthesis approaches are presented. Its applications in catalysis, thermal insulation, fire retardation, sensing and biosensing, wastewater treatment, pharmaceuticals and medicine are highlighted.

Keywords: nanocellulose, sustainable, eco-friendly. top-down, miniaturization, bottom-up, hydrolysis, ionic liquids, diverse applications

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Introduction

The interdisciplinary field of nanotechnology has witnessed considerable attention from the scientific community in the last decade. This situation is not likely to decline any time soon because of the widely held opinion that nano-based products and devices have superior properties that can be tailored for human utilization in a smarter and more environmentally benign pattern (Bulota, Maasdam and Tiekstra, 2013; Allhoff, Lin and Moore, 2012; Drexler, 1986; Matteo, Candido, Vera and Francesca, 2012; Drexler and Minsky, 1990; Moran-Mirabal and Cranstan, 2015; Iguchi, Yamanaka and Budhiono, 2000). This stance is supported by the remarkable difference, in terms of physical, chemical and biological properties which substances exhibit in the nanoscale range (1-100nm) compared to its bulk state, as well as the wide range of adaptations and applications which nanoparticles offer; from medicine, pharmaceuticals, electronics and computers to catalysis, adsorption, heat transfer, oil and gas, perovskite supported solar panels and batteries, consumer goods and biomedical devices and consumables (Sireesha, Babu, Kiran, and Ramakrishna, 2018; Seyda, 2011; Singh, Manikandan and Kumaraguru, 2010; Ye, *et al*. 2015: Singh, Ahmed and Growcock 2010).

Therefore, nanotechnology refers to the scientific miniaturization and manipulation of natural and engineered materials at the nanoscale range for diverse applications (Allhoff, Lin and Moore, 2010; Drexler, 1986; Moran-Mirabal and Cranston, 2015; Hubbe, Rojas, Lucia and Sain, 2008). Whereas nanoparticles can be defined as ultrafine particles of matter having at least two spatial dimensions in the size range of a billionth of a metre (Horikoshi and Serpone, 2013; Roco, 2011, Drexler and Minsky, 1990; Feyman, 1961; Drexler, 1986). The properties which accounts for its prominence and versatility include: large surface area versus volume ratio, reduced degree of structural defects which enhances its mechanical strength, increased array of surface exposed atoms which enhances reactivity and functionality, increased quantum effects, improved thermal and electrical characteristics, as well as corrosion resistance profile, flexibility, ease of adaptation and plasmonic effects (Xia, 2014; Yang, Hoang and Dridi, 2015; Drexler, 1992).

However, a less restrictive but vital term for the building blocks of devices, systems and products of nanotechnology is **nanomaterials.** A comparative analysis of the numerous definitions of nanomaterials proposed by various standard organisations, industries and governments are available in the literature (Beverhof *et al.,* 2015). One of such definitions adopted by the European Commission states that a nanomaterial is "a natural, incidental or manufactured material containing particles, in an unbounded state or as aggregate or as a agglomerate, in which 50% or more of the particles size distribution have one or more external dimensions in the range of 1nm - 100nm" (Beverhof, *et al.* 2015). It must be noted that the term nanomaterials encompass **nanostructures (NSs), nanostructured materials (NSMs)** and **nanocomposites (NCMs).** Nanostructures are characterized by form and dimensionality whereas the nanostructured materials are characterized by form, dimensionality and composition while nanocomposites comprise two or more of these components.

Classification Of Nanomaterials

The pioneering effort in the classification of nanomaterials, which was done on the basis of the chemical composition and dimensionality was attributed to Gleiter (Tiwari, Tiwari and Kim, 2011). However, the classification scheme presented here is on the basis of the variations in spatial dimensions which is not in the nanorange as Postulated by Pokropivny and Skorokhod (Pokropivny, *et al.* 2007). These include:-
Zero-dimensional nanomaterials (0 D): Presently, this is the simplest building blocks that can be used for nanotechnology devices and products. It includes amorphous or crystalline materials in which all the dimensions (x, y, z) are measured within the nanometric range (d < 100nm). It may be composed of a single or multi-chemical and elements and can exist individually as an entity or incorporated in a matrix or composites. Typical examples of 0D nanomaterials are molecules, nanoparticles, quantum dots, fullerenes, nanocrystalline films, nanopowders, nanoclusters and nanorings.

One-dimensional nanomaterials (1D):- These are amorphous or crystalline needle-shaped materials with one dimension outside the nanoscale range. It may be composed of one or more chemical elements and can exist individually or embedded within another medium. Examples of 1D-nanomaterials are nanofibers, nanotubes, nanorods, nanowire, nanobelts, nanoribbons, nanofilaments, nanowhiskers and quantum wire.

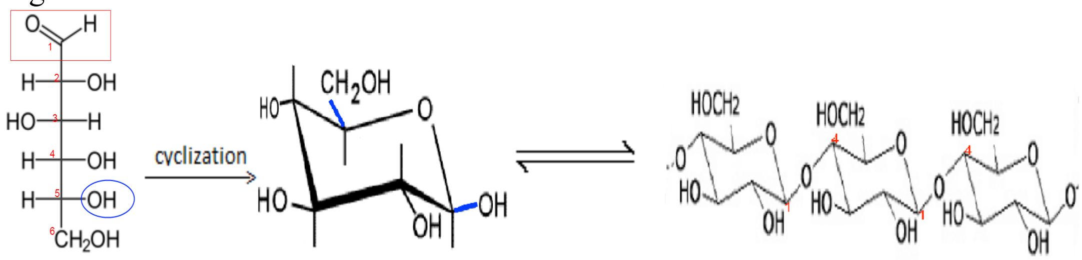
Two-dimensional nanomaterials (2D):- These set of nanomaterials are confined to the nanoscale in one dimension only. It can be amorphous or crystalline, single or multi-layered and consists various chemical components. Examples of 2-D nanomaterials include nanolayers, nanocoatings, nanoplates, nanoprisms, nanosheets, nanowalls, nanodisk, quantum well and graphene.
Three-dimensional nanomaterials (3D):- These are nanomaterials that are not confined to the nanoscale in any dimension. Typical examples are nanoballs, nanocoil, nanocones, nanopillars, multi-nanolayer, nanoflower, diamond, graphite and lonsdaleite.

Cellulose

In line with the growing demand for eco-friendly, sustainable, biodegradable and renewable raw materials for the production of equally eco-friendly goods and services, cellulose, the most universally abundant polymeric polysaccharide presents enormously viable prospects as a versatile biomaterial (Shrestha, 2010; Chirayil, Mathew and Thomas, 2014; Kiro 2015). It has been estimated that cellulose constitutes approximately 1 to 1.5×10^{12} tons of total biomass synthesized annually; including lignin and hemicellulose from the cell walls of woody plants (Klemm, Philip, Heinze and Wagenknecht, 1998; Youssef, Lucia and Rojas, 2010; Moran-Mirabel et al, 2015). Cellulose has crystalline structure, whereas hemicellulose has amorphous structure consisting of xylans, namans, β-glucans and xyloglucans. Lignin is a hydrophobic substance that can be removed by bleaching and chemical pulping (Gharenkhani, Sadeghinezhad, Kazi *et al.,* 2014). Besides, higher plants cellulose is also found in the cell walls of several marine animals, algae, bacteria, protozoa, and some invertebrates (Youssef, *et al.* 2010). Regardless of its source, cellulose consists of a long chain repeating dimers of D-glucose called pyranose, or cellobiose linked by single oxygen atoms with respect to its neighbours between C1 of the pyranose ring and C4 of the next ring. Thus, these linkages are referred to as D-1-4 linkages. Each D-1-4-glucopyranose bears three hydroxyl groups (OH^-) and can form intra- and intermolecular hydrogen bonds which plays a major role in determining the physical properties of the cellulose (Kim, Yun and Ounaies, 2006; John and Thomas, 2008; Chandrahasa, Rajamane and Jeyalakshmi, 2014; Moran, Alvarez, Cyras and Vasquez, 2008, Maleki, Mohammadi and Ji, 2016). Essentially, one of the D-glucose molecule involved flips at 180º angle to allow for the alignment of the hydroxyl groups (OH^-) alongside each other in order to combine to form the linking glucosidic bonds by condensation. The molecular formula of glucose can be represented as $(C_6H_{10}O_5)_n$; where n can assume values between 3000 and 15000 as natural polymer depending on the source (Keshk, 2014; Wang, 2009). Fig. 1 shows the different molecular structures involved in the conversion of D-glucose units to cellulose.

Many properties of cellulose depend on its degree of polymerization or chain length and degree of crystallinity, which in turn varies with source. The higher the degree of polymerization, the greater the resistance to tensile forces. High crystallinity index indicates preference in industrial utilization of the product.

Fig. 1



(a) (b) (c)

(a) D-glucose (b) D-anhydroglucopyranose (c) cellulose

This parameter can be determined using any of the following methods; density measurements, x-ray diffraction, deuterium exchange kinetics, hygroscopicity measurements, hydrolysis, periodate oxidation, substitution, spectroscopic methods – nuclear magnetic resonance (NMR), fouriers transform infrared (FTIR) and Raman vibrational spectroscopies. The response of cellulosic materials varies with different measurement techniques and the accompanying interpretations (Qingqing, 2012).

Cellulose is typically hydrophilic due to the large amount of OH^- groups it possess and can absorb or lose water with corresponding swelling or shrinkage but it is neither soluble in water nor organic solvents. As a raw material, cellulose is widely known for its application in pulp and paper, textile, foods, personal hygiene items, pharmaceuticals and biofuel processing industries (Wang, 2009).

Types Of Cellulose

Several analytical investigations have revealed that there are four polymorphic forms of cellulose, namely: CI, CII, CIII and CIV (Van der Hart and Atalla, 1984; Baker, Helbert, Sugiyama, Chanzy and Langan, 2003; Isogai, Usuda, Kato *et al.*, 1989). Based on the source, cellulose microfibrils consist of two regions; the neatly ordered crystalline region and the disordered amorphous or para-crystalline region, in a variety of shades. The CI allomorph, referred to as native cellulose comprises two distinct crystalline forms Iα and Iβ (Dufresene, 2012; Gardner and Blackwell, 1974; Van der Hart *et al*, 1984; Ciolacu and Popa, 2011; Wang, Yang, Kubicki and Hong, 2016). Cellulose Iα and Iβ can coexist in varying proportions depending on the source of cellulose. Cellulose Iα is the predominant form in algae and microbes that emit cellulose e.g. gluconacetobacter xylinum bacteria, *halicystis* (algae), *cladophora*, *sarcina ventriculi* and *valonia.* Cellulose Iβ is the predominant form in higher plants (wood, cotton, flax) and tunicates (Saxena and Brown Jr. 2001; Van der Hart et al, 1984; Keshk, 2014; Jonas, Farah and Luiz, 1998). The difference between the two varieties of native cellulose include dissimilar molecular shape, hydrogen bonding type and crystal packing type as well as the difference in the pattern of resonance around 106ppm, which is singlet for Iα but doublet for Iβ. In terms of the crystal packing, the unit cell of cellulose Iβ is monoclinic while that for Iα is triclinic crystals (Horii, Yamamoto and Hirai, 1997). Furthermore, cellulose I can be converted to other polymorphic forms via different transformation processes by contacting with certain reagents at elevated temperatures (Moon, Martini, Nairn, Simonsen, Youngblood, 2011; Tort-Agell, 2016).

Nanocellulose

Nanocellulose is a generic term used to describe cellulose-based nanomaterials. It is an emerging and sustainable raw material for the nanotechnology community (Klemm, *et al*. 2011; Charreau, Foresti and Vasquez, 2013; Milanez, Amaral, Faria and Gregolin, 2013; Araujo, Mohajan, Kerr da Silva *et al.,* 2012).

Besides being in the nanoscale range, nanocellulose exhibit potentially versatile characteristics which is viewed by various researchers as the aggregation of advantages over the inorganic counterparts, namely (Klemm, Heublein, Fink and Bohn, 2005; Liu, Deng, Ma and Brian, 2015; Abdul-Khalil, Davoudpour, Nazuruyl *et al.,* 2014; Bulota, Krieitsmann, Hughes and Paltakar, 2012; Saito, Kuramae, Wohlert *et al.,* 2013; Tanpichai, Quero, Nogi and Yano, 2012)
(i) Renewability and biodegradability,
(ii) Wide range of options globally,
(iii) Potential of engaging local farmers,
(iv) Ease of production,
(v) High capacity to interact with neighboring molecules,
(VI) low cost of production,
(vii) Low energy demand,
(viii) Low density,
(ix) Improved mechanical properties (e.g. young modulus, magnetic properties, stiffness, high aspect ratio),
(x) Improved thermal capacities and
(xi) Improved reactive surface

Presently, three categories of nanocellulose had been synthesized, namely: cellulose nanofibers or nanofibrillated cellulose (NFC), cellulose nanocrystals or nanowhiskers or nanocrystalline cellulose (NCC) and bacterial nanocellulose (BNC) (Klemm et al., 2011; Lavoine, Desloges, Dufresne and Bras, 2012; Quero, Nogi, Yano *et al.*, 2012; Goncalves, Cruz, Sales *et al.,* 2016; Vora and Shah, 2015).

NFC: The major industrial source of fibrillated nanocellulose is wood fiber. It can be described as a long, thin and flexible nano-cellulosic particle composed of alternate crystalline and amorphous regions having dimensions in the range of 20-50nm in width and 500-2000nm in length (Moon, Martini, Nairn *et al.,* 2011; Kangas, Lahtinen, Sneck *et al.,* 2014; Kargarzadeh, Ioelovich, Ahmad *et al.,* 2017).

NCC: Nanocrystalline cellulose are highly crystalline (90%) and elongated rod-like particles with limited flexibility. It can be obtained from a wider variety of sources than NFC including plant, tunicate- algae- and bacterial-based cellulose as well as commercial micro-crystalline cellulose. The dimensions of the particle sizes can be in the range of 5-50nm in diameter and 100-500nm in length. However the dimensions and degree of crystallinity depends on the source of the cellulose and extraction conditions (Habibi, Lucia, and Rojan, 2010; Abdul-khalil, Davoudpour, Nazuruyl *et al.,* 2014; Abitol, Rivkin, Cao *et al.* 2016).

Its high crystallinity renders it nearly defect free structurally, which confers on it superior mechanical properties suitable for its usage as reinforcement nanofibres. For example, the young modulus of elasticity for cotton and tunicate derived nanocrystalline cellulose had been reported as 105 GPa and 143 GPa respectively, while the theoretical value is estimated to be 167.5 GPa (Kangardeh, Ioelovich, Ahmad *et al.,* 2017; Chauhan and Chakrabarti, 2012; Panaitescu, Frone, Ghiurea *et al.,* 2011).

The tensile strength, modulus of elasticity and density of nanocrystalline cellulose and other materials are shown in Table 1.

Table 1: Properties of nanocrystalline cellulose relative to other materials (Chauhan and Chakrabarti, 2012)

Material	Tensile strength (GPa)	Elastic modulus (GPa)	Density (kg/m^3)
NCC	7.5	120 - 143	1500
Glass Fiber	8.4	86	2500
Steel Wire	4.1	207	7850
Graphite Whisker	0.021	410	1800
Nanotube	0.011 - 0.063	270 - 970	1330
Kevlar	0.005	124	1400

It must be mentioned that though both NFC and NCC differ in the degree of crystallinity, strong acid, alkali or some other solvent is required to break down the vegetal matrix of pectin, lignin and hemicellulose which makes up the skeletal framework of the cellulose in both cases.

BNC: Bacterial nanocellulose derives its identity from the methods of production, which can be described as an extracellular, non-photosynthetic fermentation process. This process enhances the biocompatibility as well as supports the economical and eco-friendly profile of BNC (Jozala, Lencastre-Novaes and Lopez, 2016; Keshk, 2014; Siquera, Bras, and Dufresne, 2010; Iguchi, Yamanaka, and Budhiono, 2000; Bae and Shoda, 2005).

BNC particle is an organized network of extremely fine, pure and dimensionally uniform ribbon-like structure. It has the same chemical composition as plant cellulose but without the carboxyl or carbonyl groups which are usually introduced to the wood or plant derived cellulose during the purification process (Stevanic, *et al*. 2011).

It had been reported to assume average dimensions in the range of 20-100 nm in width, density of 1600kg/m^3 and modulus of elasticity of 28 GPa (Kamel, 2007; Abitol et al, 2016).

The properties which differentiate BNC from NFC and NCC are its biosynthetic origin, stable nanofibers network, moldability during biosynthesis, non-cytotoxicity and non-genotoxicty, high purity, high resistance to degradation, high polymerization degree and excellent mechanical strength while flexible in the wet state. These properties inspire its novel applications as wound-dressing materials, artificial blood vessels, artificial skin, fuel cell membranes, films for electronic appliances, ,biosensors, electrochemical lithium ion battery, purification of drinking water, air cleaning, contact lenses, cornea replacement, drug delivery and scaffolds for tissue engineering (Qingqing, 2012; Moniri, *et al*. 2017).

Synthesis

There are two broad categories of preparing nanocellulose, namely: top-down and bottom-down approaches (Moon, Martini Nairn *et al.,* 2011). The top down approach which obtains nanocelluloses by extracting cellulose particles from different sources at nanoscale, can be subdivided into three subcategories: mechanical, chemical and mechanical-chemical methods. The bottom-up approach assembles cellulose nanostructures either from the solution state of the cellulose molecules or from biosynthesis process (Klemm, *et al*. 2011). Through either "extraction" or "assembly", nanocelluloses are relatively uniform particles with enormously expanded surface area, which brings in many of the favourable properties that enhances its diverse and novel applications.

Top-down approach

The top-down approach starts with a raw material like woodchips, cotton litters, etc. From these sources, mechanical, chemical or mechanical-chemical methods are used to liberate cellulose microfibrils and nanocelluloses from the native cellulose structures. For high purity raw materials like cotton litters, this means to release individual microfibrils from the large fiber bundles whereas for the raw materials existing in natural composite form e.g. wood chip, the top-down approach means to separate cellulose from its lignin-hemicellulose matrix to derive nanocelluloses particles (Moon, *et al*. 2011).

Mechanical Methods

These processes mainly result in the production of NFC.
High pressure homogenization process: This process utilizes a high pressure homogenizer (50 - 2000MPa) to convert different types of pulp to net-like nanostructures ranging from 25 - 100 nm in the dry state by several passes. The major challenge with this process is its large energy consumption which could be as high as 70,000 kWh/t (Klemm *et al*., 2011; Spence, Venditti, Rojas *et al.,* 2011; Lavoine, Desloges, Dufresne and Bras, 2012). To overcome this problem, the pulp can be subjected to prior pre-treatment with acid hydrolysis, enzymatic hydrolysis or oxidation which can result in the reduction of energy consumption to about 2,000 kWh/t.

Grinding: A typical grinding equipment for cellulose fiber fibrillation as developed by Masuko (Tokyo, Japan) consists of two grinding stones with countersense rotation capabilities. The cellulose slurry is passed between a static grinding stone and a rotating grinding stone revolving at about 1500rpm, severally until the desired dimensions in the nano-range is obtained and further size reduction can no longer be achieved. The basic principle involves the breakdown of cell wall owing to the shearing force generated by the grinding stones (Kargarzadeh, Ioelovich, Ahmad *et al*., 2017; Missoum, Belgacem and Bras, 2013; Lavoine *et al*., 2012). Wet grinding is preferred because it prevents agglomeration and promotes effective dispersion of the created nano-cellulose particles. It also prevents the inhalation of respirable particles.

Sonocation: Sonocator utilizes ultrasound power to induce the formation of nanofibrils from cellulosic fibers. A typical sonocation system is made up of three major components; generator, converter and horn/probe. It is equipped with bottons to facilitate the control of the sonocation parameters. The generator transform alternating current to high frequency electrical energy at high voltage pulses (≈1200W) with a frequency of 20 KHz to drive the piezoelectric converter. The converter transforms electric energy to mechanical vibrations which is amplified down the length of the probe. There are two types of sonocation methods namely; direct and indirect sonocation. The amplified vibration energy can either be transmitted directly into the sample with high intensity during direct sonocation process or the ultrasonic energy can be transmitted from the probe through water medium into the sample vessel or multiple sample tubes during the indirect sonocation process. In this case, actual contact between the probe and the sample is eliminated. Any of these processes can induce the formation of nanofibrillated cellulose (Dufresne, 2012).

Cryo-crushing: Cryo-crushing refers to the process of crushing cellulosic fibers which had been frozen with liquid nitrogen to liberate the fibrillated cellulosic fibers. A typical cryo-crusher is equipped with two grinding stones, a stator and a rotor capable of revolving at 1500rpm. The dimensions of the derived fibrillated cellulose fibers depends on the source of the native cellulose but usually in the nano-range of 5-100 nm in diameter. The major drawback of this technique is the high energy requirement

(Chirayil, Matthew and Thomas, 2013; Missoum, Belgacem and Bras, 2013; Kumari, Sreenivasalu and Reddy, 2016).

Refining: Pulp refining is a widely practiced technique in the pulp and paper industries to improve pulp quality by changing the fiber characteristics. The most commonly used laboratory refiner is the PFI mill. In this device the pulp is refined between a stainless steel roll with bars and a rotating disk with a smooth bed where the pulp is distributed evenly over the disk wall. Both elements rotate in the same direction but at different speed (Gharehkhani, *et al*. 2014; Kerekes, 2005).

Chemical Methods

The cardinal procedure in the chemical treatment methods is the acid hydrolysis, which leads to the synthesis of mainly nanocyrstalline cellulose (NCC). It is usually preceeded by pre-treatment processes e.g. purification of the raw cellulosic material, treatment with alkali to increase surface area and render the fibers more prone to hydrolysis as well as disrupt lignin structures and/or treatment with a bleaching agent e.g. H_2O_2, O_2, O_3, Cl_2, $NaClO_2$ or ClO_2 to remove lignin and other impurities in order to obtain cellulose. Subsequently, the acid hydrolysis step is usually succeeded by appropriate mechanical treatment for proper dispersion of the derived cellulose (Dufresne, 2012).

Acid hydrolysis

Acid hydrolysis is the process in which a protic acid is used to catalyse the cleavage of a chemical bond via nucleophilic substitution reaction, accompanied by the addition of water molecules. Specifically, when a certain strong mineral acid (6-8M) under controlled temperature, time, agitation and acid/cellulose ratio conditions, is contacted with cellulose, the long chain of **β**-1,4 - glucosidic bonds becomes fragmented into shorter chain lengths with the addition of water molecules. The various types of acid which had been used for this purpose include sulphuric acid (often the preferred choice), hydrochloric, nitric, phosphoric, hydrobromic, hydroflouric, maleic, formic and oxalic acids (Kargarzadeh, Ioelovich, Ahmed *et al.,* 2017; Brinchi *et al*., 2013). The acids predominantly hydrolyse the disordered amorphous region leaving the stable crystalline region which can be recovered as rod-like crystalline particles. The study of the effects of higher concentrations, longer reaction times and higher temperatures reveal that nanocrystalline cellulose so derived will have lower yield, decrease crystallinity and degree of polymerization (DP) but higher surface charge and narrower sizes (Kargarzadeh *et al.,* 2017; Ioelovich, 2012). However, the drawback to acid hydrolytic processes are corrosion of reactors and equipment, poor catalyst recyclability, product separation and hazardous effluent treatment and high cost of production. It has been well documented in the literature that various solid acids can be used to minimize some of the problems encountered with this approach. Some examples of solid acids used for the hydrolysis of cellulose are phosphor-tungsten acid ($H_3PW_{12}O_{14}$), sulphonated carbonaceous based acids, polymer based acids and magnetic solid acids (Huang and Fu, 2013; Kargarzadeh *et al.,* 2017). Alternatively, several time consuming and environmentally harmful steps associated with mineral acid hydrolysis can be avoided by using certain gaseous acids e.g. gaseous nitric, hydrochloric or triflouroacetic acids. For effectiveness, moist cellulose is required. This will minimize the large amount of water usually needed for the purification of products, eliminate the dialysis step encountered with mineral acids and acid recycling becomes easy (Kargarzadeh *et al.,* 2017).

Enzymatic hydrolysis

Enzymatic hydrolysis is the process in which enzymes are used to facilitate the cleavage of bonds in organic molecules, accompanied with the addition of water molecules. In the case of cellulose, these sort of enzymes are called cellulase and are of fungal origin. Enzymatic hydrolysis is an important pretreatment step if significant reduction in energy consumption is desired since it is nature inspired. Microfibrillated cellulose (MFC) obtained enzymatically from pretreated wood fibers had been reported to show more favourable structure in terms of length and aspect ratio than MFC obtained from strong acid hydrolysis (Islam, Alam, Patrucco *et al.,* 2014; Mossoum, Belgacem and Bras, 2013; Janardhanan and Sain, 2006).

TEMPO-mediated oxidation

TEMPO-mediated oxidation is one of the most promising methods of obtaining cellulose nanofibrils. Essentially, it entails the oxidation of cellulose fibers by adding $NaClO_2$ or NaClO (oxidant) to aqueous cellulose suspensions in the presence of a nitroxyl radical such as 2, 2, 6, 6 - tetramethylpyperidine-1-oxyl as catalyst and halogen salt (e.g. NaBr) in alkaline medium. Subsequently, the aggregating nanofibers can be disintegrated by mechanical agitation with the aid of a waring blender. the TEMPO-mediated oxidation based nanocrystalline cellulose possesses higher viscosity, higher shear stress, higher carboxylic groups, improved transmittance and smaller sizes of oxidized NCC particles compared to conventional hydrolysis based NCC (Qian, Tang and Chen, 2011; Tang, *et al*. 2017; Missoum Belgacem and Bras, 2013).

Carboxymethylation Process

The procedure aims at introducing functional groups to the cellulose backbone. It can be affected by the reaction of monochloroacetic acid or its sodium salt (sodium monochloroacetate) under alkaline condition, in the presence of an organic solvent (isopropanol). Therefore, carboxymethylation of cellulose fibers promote the individualization of nanofibrils as wells as increase the number of anionic carboxyl groups on the fibrillated celluloses, thereby increasing its capacity to bond to cationic materials (Mohkani and Talaeipour, 2011; Asi, Mousavi and Labbafi, 2017).

Acetylation Process

Acetylation of cellulose fibers is another surface modification technique carried out to improve its dispersability and compatibility in other polymeric matrices as reinforcing materials. The principle behind this process is to react the hydroxyl groups (OH-) of the fiber constituents with a coupling agent having acetyl groups (CH_3CO-) e.g. acetic anhydride the reaction may be sped up by a suitable catalyst (Bledzki, Mamum, Lucka-Gabor and Gutowski, 2008; Islam, Alam, Zoccola, 2013; Beztout, Boukerrou, Djidjelli *et al.,* 2015).

Chemical-Mechanical Approach

The chemical-mechanical approach refers to the amalgamation of one or more chemical pretreatment methods with mechanical disintegration techniques. Figure 4 is the flow diagram of a typical chemical-mechanical nanocellulose preparation procedure (Dufresne, 2012).

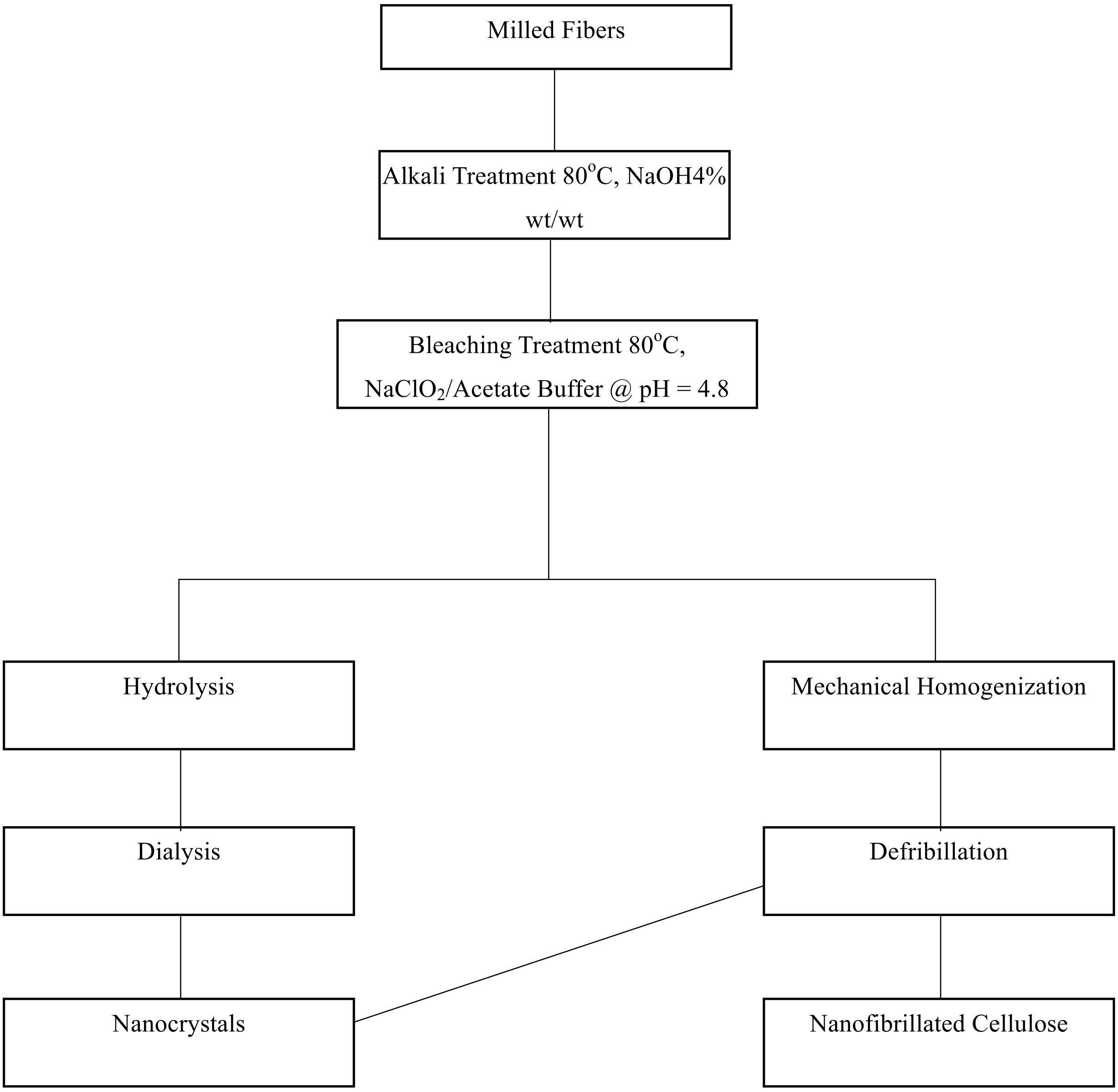


Figure 4: Typical chemical-mechanical procedure for the synthesis of cellulose (Dufresne, 2012).

Bottom-Up Approach

The Bottom-Up Approach can generally be viewed as the assemblage techniques where substances at atomic and molecular scales are stacked on each other to yield relatively uniform and rather consistent nanofibers. Typical examples of the bottom-up methods for nanocellulose synthesis are electrospining and bacterial biosynthesis

(Dufresne. 2012).

Electrospinning

A typical electrospinning equipment consists of a metering syringe pump equipped with a spinneret, a pippete and complimentated with a high voltage DC power supply and a collector screen (target) for the propagation of nanocellulose fibrils. During the process, a sufficiently high voltage (30KV) is imposed on a droplet of polymer solution held by surface tension at the end of the capillary, which stretches the droplet to a crititical point where it tapers to a conical shape called Taylor cone. At this point, the electrostatic force overcomes the surface tension of the droplet and a stream of liquid erupts from the surface. The solvent evaporates while the jet is on flight leaving the ultrafine polymeric fibers measuring 10-100nm in diameter on the target. Dissolution of cellulose can be achieved with the acid of the derivatizing solvents or non-derivatizing solvents. The dissolved cellulose or polymer solution becomes the raw material for the electro-spinning process. Derivatizing solvents induces covalent modification on the cellulose backbone while non-derivatizing solvents separate the individual cellulose chain from each other without chemical modification. Some examples of the widely used solvents are: - dimethylacetamide or DMAC/LiCl, NaOH/Urea/Water; n-methylmorpholine oxide (NMMO)/Water or ionic liquid. The morphological features of the electrospun nanofibers depends on the effect of various process parameters including electric field strength, tip-to-collector distance, polymer solution feed rate and composition (Rebouillat and Pla, 2013; Kargarzadeh, 2017).

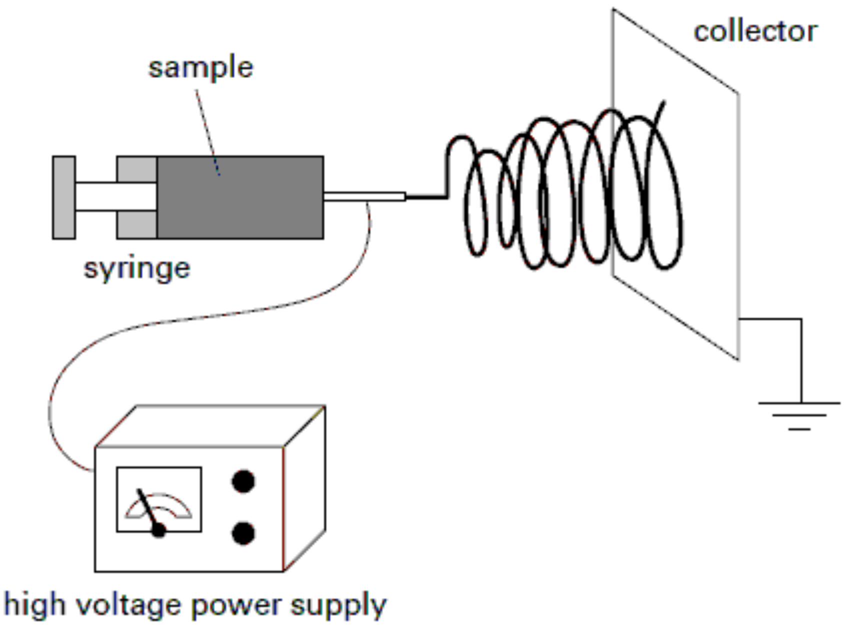


Figure: An electrospinning set-up (Alain Dufresne, 2012)

Bacteria Synthesis: The metabolic processes of certain aerobic bacteria (e.g. gluconacetobacter xylinus) can convert low molecular weight sugars and alcohols to cellulose molecules free from lignin and hemicellulose components found in plant cellulose. This simple purification process can remove all impurities leaving pure nanocellulose fibers. BNC has the same chemical composition as plant cellulose, but without the carboxyl or carbonyl group which are usually introduced to wood or plant derived cellulose during the purification process (Stevanic *et al.* 2011; Dfresne, 2012;

Ashajaran Yazdanshenas, Rashidi *et al.,* 2013)

Applications Of Nanocellulose

Paper, Absorbent Prod ucts and Cosmetics
Paper and paperboard industries are the traditional users of cellulose and nanocelluloses. Particularly, nanocellulose offer strong reinforcement and barrier effects on paper materials. Its capacity to absorb water makes it a suitable candidate for the manufacturing of various absorbents. It can also be used as composite coating agent in cosmetics, for example hair, eyelashes, eyebrows and nails (Eriksen, Syverud, Gregersen, 2008).

Waste Water Treatment

Usually industrial effluents contain various kinds of contaminants depending on the processes and operations applicable. Such impurities include metal ions, humic acids, inorganic and organic particles, fine suspended solids, dissolved solid and other impurities. The development of various nanocellulose adsorbents for the removals of such toxic pollutants are well documented in literature.(Fu and Wang, 2011; Gupta, Tyagi, Salegh *et al.,* 2015; Charpentier, Neville, Lanigan *et al.,* 2016; Viosin *et al.,* 2017).

Jebali *et al*. (2015) reported on the adsorption of humic acid with the aid of amine-modified nanocellulose. Bagheri *et al*., (2017) separated water and ethanol with the aid of the membrane derived from bacterial cellulose.
Catalysis: the quest for greener and cleaner environment requires thorough chemical processes that are devoid of hazardous waste generation. Conventional catalysts are often non-biodegradable, non-toxic and non-renewable. Green catalysis is a subset of catalysis concerned with the philosophy, design, synthesis and application of eco-friendly catalysts (Atabay and Ersoz, 2016; Lu and Ozcan, 2015).

The superior attributes of nanocellulose, namely; high surface area, thermal stability, abundant hydroxyl and sulphate ester groups, capability of forming stable suspension in water, biodegradability, non-toxicity and sustainability potential make it quite suitable in catalyst systems (Kaushik and Moores, 2016). Nanocellulose usually serve as a catalyst support, in order to hinder aggregation of nanoparticles either as metal or metal oxides. Examples include precious metal (Au, Ag, Pt and Pd) - nanoparticles/nanocellulose composite (Wei, Rodriguez, Rennecker and Vikesland, 2014). The advantage of highly dispersed inorganic nanoparticles is to ensure efficient contacting between reacting species, resulting in increased rate of reaction. (Bagheri, Julkapli and Mansouri, 2017).

Energy and electronics

It had been reported by Wei *et al.* (2014) that:

(i) Nanocellulose can be used as a raw material for rechargeable energy storage devices in Lithium-ion batteries.

(ii) Pd-NP/BC nanocomposite can be used as membrane electrode assembly (MEA) in fuel cell, and

(iii) Transparent nanocellulose-paper based solar cell which showed significant power conversion efficiency had been designed.

Bacterial nanocellulose membrane are used to manufacture paper diaphragms for loud speakers and headset of electronic devices (Sukara and Meliawati, 2014).

Nanocellulose Concrete

Nanocellulose can be used as an effective and eco-friendly replacement for hazardous asbestos fibers and glass fibers as concrete composite reinforcement because of its improved mechanical and physical properties (Bagheri *et al*., 2017).

Thermal Insulation

The thermal conductivity of native cellulose based insulating material is 40mW/mK while a thermal conductivity of less than 25mW/mK had been reported for nanocellulose derivatives which qualifies them as super-insulating materials. (Lavoine and Bergstrom, 2017).

Fire Retardation

The limiting oxygen index of most fire retardants is in the range of 22-25 LOI, while nanocellulose foam laced with inorganic fillers (clay or graphene) with a limiting oxygen index of 34 provides a better option (Lavoine and Bergstrom, 2017).

Nanofluids: nanofluids refer to fluid suspension of nanomaterials. The evaluation of the application of nanocellulose fluids as well as its chemically modified counterparts as a 'green' flooding agent in enhanced oil recovery is well documented in literature (Qinzhi, Bing, Yan *et al.,* 2016; Wei *et al.,* 2016; Xiaofei, Yanyu, Guangpeng and Zhiyong, 2017).

Sensing and Biosensing

Nanocellulose based technology has become an emerging platform for the fabrication of efficient, simple, cost-effective and disposable optical/electrical devices for several sensing applications ranging from environmental monitoring, health care diagnostics, food quality control and forensic analysis. (Golmohammadi, Morales-Narvaes, Naghadi and Merkoci, 2017; Weishaupt *et al.* 2016).

Biomedical Applications

Bandages obtained from BNC is used for wound dressing, skin grafting and treatment of various other injury sites (Meftahi, Khajavi, Rashidi, *et al*. 2009). It is also applied in several other tissue engineering treatment such as bone and cartilage grafts, contact lenses, cornea replacement, cardiovascular, trachea, artificial blood vessel and many other tissue scaffolds, reconstruction or regeneration treatment in humans (Czaja, Young, Kawecki, Brown, 2007; Moniri, *et al*. 2017).

In the pharmaceutical industry, nanocellulose is used as excipients for drug delivery (Ul-Islam, Khattak, Khan *et al*.,2015).

Conclusion And Future Prospects

The present day mantra for the advancement of science and technology in the phase of growing ecological and social awareness fueled by the precarious impacts of the exploration, exploitation and the uncertainties bordering the pricing of fossil fuel, is the adoption of "green and clean technological approaches to goods and services". This has in turn inspired research in the direction of "green" raw materials for diverse applications. Nanocellulose comprising nanofibrillatd cellulose, nanocrystalline cellulose and bacterial nanocellulose are important integral of the aggregating ideas as emerging and sustainable raw materials for the nanotechnology community. The relevance of the candidacy of nanocelluloses is attributable to its sustainability, biocompatibility, biodegradability, high aspect ratio, transparency, hydrophilicity and non-toxicity.

Due to the interdisciplinarity of nanoscience, effectively coordinated synergy is necessary for the transformation of bench-scale researches to rewarding investments commerce, devoid of safety, health and environmental (SHE) concerns.

In a nutshell, it is safe to opine that the world is currently awaiting nanocellulose-enabled body parts of automobiles, aircrafts, flexible electronic displays, light weight military armour, artificial organs and many more.

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Hydrological Vulnerability Assessment of Landfill Site Using GIS: A Case Study of Alimosho Landfill Site

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Abstract
Solid wastes are disposed in landfills where it decomposes and produces leachate that can contaminate underlying groundwater. This study investigated the effects of open landfill sites on the underground water quality using the DRASTIC L model based on eight parameters. Water samples were collected using systematic random sampling method from hand-dug wells around the Solous landfill sites in Igando, Alimosho Local Government Area of Lagos State and analysed. A total of thirteen hand-dug wells were sampled at increasing distances from the landfill site and analyzed for heavy metals. A GARMIN GPS was used to record the latitude and longitude of sampling points which were subsequently imported into a GIS environment and parameters integrated to analyse for vulnerability sensitivity. The results showed that out of a total area of 166.657 hectares under study, about 54.013 hectare were found to be within the low vulnerable zone with a DRASTIC index range between 101 - 123, about 52.225 hectares were observed to be in the moderately vulnerable zone with an index ranging between 123 and 135. About 60.417 hectares were located in high vulnerability zone with an index ranging between 135 and 154.The result of the water analysis showed that Zinc had the highest concentration; Chromium was not found present in any of the wells sampled. It is concluded, that the groundwater in the study area has been contaminated. There is therefore the need for adequate and proper planning and strategic management for disposal of waste within the study area.

Keywords: Landfill, leachate, vulnerability mapping, infiltration, dumpsite, GIS, DRASTIC, groundwater, pollution

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Introduction

According to (Smith, & Edger, 2006), water is said to be the most abundant environmental resource on planet earth, however, its accessibility is dependent on its quality, quantity and availability. It may be available in various forms and quantity but its usefulness for various purposes is highly dependent on its quality. The human body consists of 70% water while 60-70% of plant cells are made up of water (Smith, & Edger, 2006).

Diseases are likely to spring up through water pollution, especially groundwater contamination, which can rapidly spread beyond human expectation because of its flow mechanism (Afolayan, *et al.,* 2012). Water is one of the major factors that make this planet we live in habitable for humans. Since water forms the major component of plant and animal cells, it is the basis of life and therefore its quality cannot be neglected.

The rapid growth of cities in the developing world in recent times has resulted in increased consumption of resources to meet the growing demands of urban population and industry. This has led to generation of large amounts of municipal solid waste which are collected and disposed in sites designated as landfills. The waste on these landfill sites leaks and this leakage is capable of polluting the underground water. The landfills are made up of a variety of hazardous chemicals, contaminants and non-contaminants, which constitute a threat to groundwater quality (Imoke & Effiong, 2011). When rain drops and infiltrates the soil, harmful substances from these landfills find their way into ground water, thereby polluting the aquifer and making it unhealthy for domestic and other purposes. A release of leachate to underground water poses several risks to human health, destruction to the environment, and increases toxicity in the environment. The toxicity in the environment is affected by the underlying materials of the landfill sites, the hydraulics of the groundwater system and the chemistry of the leachate (Carter and Parker, 2009). The aim of this study to determine hydrological vulnerability assessment of Solous landfill sites in Igando, Alimosho Local Government Area of Lagos State, Nigeria; identify locations of well points that are vulnerable due to the land fill sites and apply DRASTIC L model to analyse hydrological impart of the landfill in the study area.

The DRASTIC model is a method developed by the service of the American Agency of environmental protection USEPA (Aller, *et al.,* 1987) which estimate the potential for pollution and assesses the vertical groundwater vulnerability (Secunda, *et al.,* 1998). This model takes into account most of the hydrological factors that affect and control the flow of groundwater (Muhammad, *et al.,* 2015). The seven index weighing parameters from the word 'DRASTIC' are: D - Depth of water table, R - recharges (net), A - Aquifer media, S - Soil media, T- Topography, I - Impact on vadose zone, C – Conductivity. The eighth parameter is Distance (L) which is the addition that makes the model to be modified to DRASTIC L. In this study, DRASTIC L model was used because it combines the model with distance to landfill site to reflect its peculiarity for the landfill site.

Materials and Methods

Study Area

The study area (shown in Figure 1) is located in Lagos, Nigeria. The area is bounded in the North and West by River Owo and IfakoIjaiye, Agege respectively. It is bounded in the East by Ikeja Local Government Area while it is bounded in the South by Oshodi/Isolo, Amuwo-odofin and Ojo local Government Area. The study area, Alimosho Local Government Area is the largest local government in Lagos state within latitudes 6°33'46" N and 6°39'54"N and longitudes 1°41'7" E and 1°48'32" E. It has a total population of 1,362,077, land area of 185 km2 with average density of 713 persons per square kilometre approximately. The study area has a temperature range of 28 0C to 33 0C. It is characterized by swamp forest and coastal plains especially in the riverine and coastal parts. The subsurface geology reveals two basic lithologies; clay and sand deposits. These deposits may be inter-bedded in places with sandy clay or clayey sand and occasionally with vegetable remains and peat (Ayolabi & Peters, 2005).

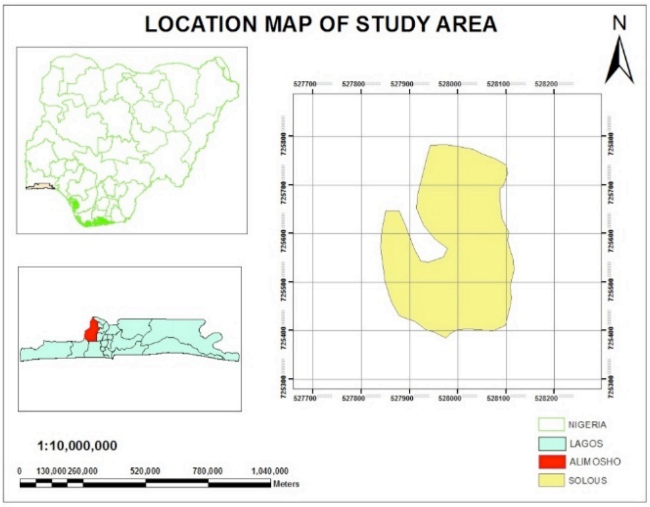

Figure 1: The Study Area

Data Acquisition

A preliminary inspection of Solous landfill site in Igando Local Government to obtain geographical information and similar data prior to a detailed survey was conducted. A GARMIN GPS was used to record the latitude and longitude of sampling points, which were imported into the ArcGIS environment. Topographical data for this research was collected from the Office of Surveyor General of Lagos State. The meteorological data (daily and monthly rainfall) for a period of 2000-2015 were collected from Nigerian Meteorological Agency (NIMET), Lagos State. The various data types used for this study and their respective sources are given in Table 1.

Table 1. Data Used and Sources

Data type	Sources	Output layer
Water level	Water level measurement	Depth to water (D)
Average annual rainfall	Nigerian Meteorological Agency (NIMET)	Net recharge (R)
Geology table	Oluwapelumi O, Bankole T. 2013.J Environ Pro 4, 454-465	Aquifer media (A)
Soil table	Oluwapelumi O, Bankole T. 2013.J Environ Pro 4, 454-465	Soil media (S)
Topographic data	Office of the Surveyor General of Lagos State.	Topography (T)
Geology table	Oluwapelumi O, Bankole T. 2013.J Environ Pro 4, 454-465	Imapact of vadose zone (I)
Hadraulic conductivity	Oluwapelumi O, Bankole T. 2013.J Environ Pro 4, 454-465	Hydraulic conductivity (C)
Distance	ArcGIS measure tools	Distance (D)

Data Processing

Eight parameters were weighted and rated according to their relative susceptibility to the pollutant and relative contribution to the potential contamination. Modified DRASTIC (DRASTIC L) assigns weights and ratings to each of the eight parameters, each is classified into classes on the scale of 1-10, in which one (1) denotes least vulnerable while (ten)10 most vulnerable areas. This rating was further scaled into weights (1-5) based on the importance of the parameter in determining aquifer characteristics. Weight one (1) is least significant and weight five (5) is most significant. The ratings and weights of the eight parameters are shown on Table 2. (Table 2).The coordinate of the entire sample were imported into ArcGIS 10. Interpolation was performed by using inverse distance weight (IDW) to covert the table to raster for effective processing. The area of interest (AOI) was extracted from the boundary shapefile. The extracted raster was reclassified (Table 2) and the rate (R) and weight (W) added for further analysis of other parameters (Figure 2).

Table 2. Ratings and Weights of Eight DRASTIC L Parameters

Drastic L Parameter	**Range**	**Ratings**	**Drastic L Weight**
Depth to water (m)	0 - 2 2 - 10 10 - 20 20 - 40 40 - 60 >60	10 8 6 4 2 1	5
Net recharge (mm/yr)	800 - 900 901 - 1000 1001 - 1100 1101 – 1200 1210 – 1300 1301 – 1400 1401 – 1500 1501 – 1600 1601 – 1700	1 2 3 4 5 6 7 8 9	4
Aquifer media	Sandy clay Silty sand & sand Sand, gravel and sandy clay Sand Sandy gravel Gravel	1 2 4 6 8 9	3
Soil media	Clayey loam soil Clayey soil Silty clay loam soil Silty loam Sandy clay loam soil Sandy clay soil Sandy loam soil Cliffs	2 3 4 5 6 7 8 9	2
Topography	1 – 2 % 2 – 6 % 6 – 12 % 12 – 18 %	10 9 5 1	1
Impact of vadose zone	Confined aquifer Sandy clay and sand Sand	1 5 6	5
Hydraulic conductivity	$1 \times 10^{-6} - 5 \times 10^{-5}$ $5 \times 10^{-5} - 2 \times 10^{-4}$ $2 \times 10^{-4} - 4 \times 10^{-4}$ $4 \times 10^{-4} - 5 \times 10^{-4}$ $5 \times 10^{-6} - 1 \times 10^{-3}$	1 2 4 6 8	3

Distance from landfill site (m)	350 – 500	1	4
	500 – 600	2	
	600 – 700	3	
	700 – 800	4	
	800 – 900	5	
	900 – 1000	6	
	1000 – 1100	7	
	1100 – 1250	8	
	1250 – 1350	9	
	1350 – 1450	10	

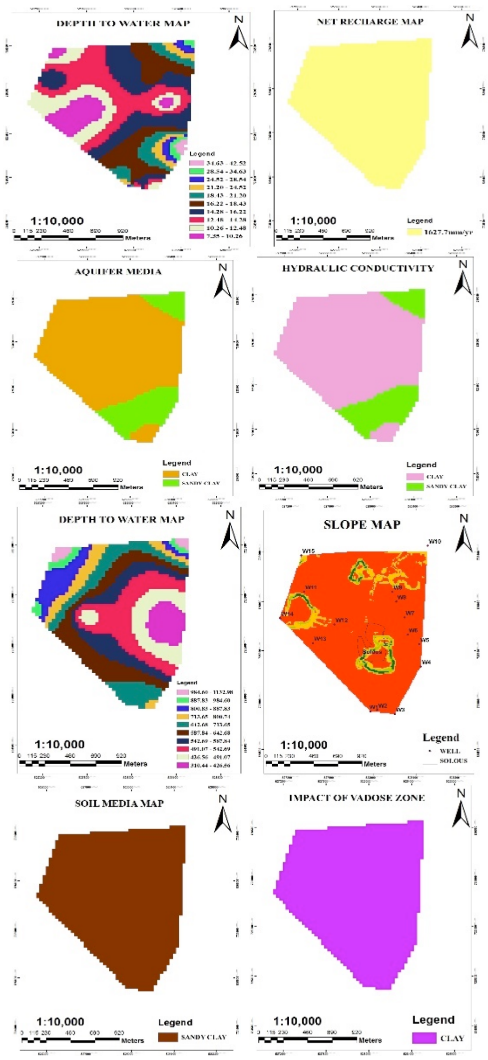

Figure 2. Map showing all the Eight Vulnerability Index

Final Vulnerability Map

The DRASTIC vulnerability index (DVI) was calculated by linear addition of the weights and rating of each factor of vulnerability using the command lookup in ArcGIS raster calculator. The ArcGIS raster calculator is given by the following formula:

DrDw+RrRw+ArAw+SrSw+TrTw+IrIw+CrCw+LrLw (1)
Dr=depth rating
Dw=depth weight
Rr=net recharge rating
Rw=net recharge weight
r=aquifer rating
Aw=aquifer weight
Sr=soil rating
Sw=soil weight
Tr=topography rating
Tw=topography weight
Ir=impact of vadose zone rating
Iw=impact of vadose zone weight
Cr=hydraulic conductivity rating
Cw=hydraulic conductivity weight
Lr=distance rating
Lw=distance rating

The final vulnerability map was then produced by adding all the factors of vulnerability together in equation (1). Figure 3 shows the vulnerability map.

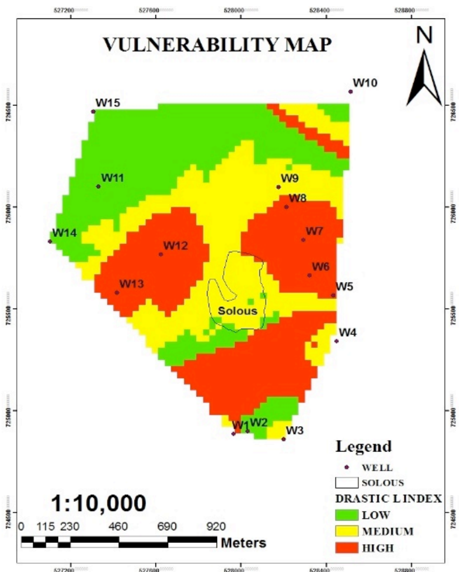

Figure 3. Vulnerability Map

The DRASTIC index values indicates that a range between 101 and 123 is considered to have low vulnerability, while a range between 123 and 135 indicates moderate vulnerability. An area is considered to be highly vulnerable if its range falls between 135-154 indexes.

Data Sensitivity Analysis

The sensitivity analysis is performed to clear the doubt of the argument of certain scientists who believe that groundwater vulnerability can be worked out without using all the parameters of DRASTIC L model. Some others have also in their opinion said the rating and weight are subjective and there is reason to doubt the accuracy of the DRASTIC L model.

In the first instance the rated parameters of the model have been examined for interdependence and variability as a high degree of interdependence of the parameters may lead to the risk of misadjustment (Babiker, *et al.,* 2005; Rosen, 1994).

There are two sensitivity analyses tests.

The first test identifies the sensitivity of vulnerability map by removing one or more layer maps and is worked out using the following equation:

S=100*((V/N-V^'/n)/v) (2)

where S is the sensitivity measure, V and V^'are the unperturbed and the perturbed vulnerability indices respectively, and N and n are the number of data layers used to compute V and V^'. The unperturbed vulnerability index is the actual index obtained by using all seven parameters and the perturbed vulnerability index was computed using a lower number of parameters. The second sensitivity analysis test is the single parameter sensitivity test, carried out to assess the influence of each of the seven parameters of the model on the vulnerability measure. In this analysis, real or ‘‘effective’’ weight of each parameter was compared with its assigned or ‘‘theoretical’’ weight. The effective weight of a parameter in a sub-area was calculated by using the following equation:

W=(PrPw/V)*100 (3)

Where W refers to the “effective” weight of each parameter, Pr and Pw are the rating values and the weight for each parameter. V is the overall vulnerability index.

Groundwater Test from Wells for Model Check

Wells are hand dug or machine assisted dug holes in the ground to locate the presence of drinking water. These wells are sometimes used directly or as boreholes and connected by pipes to households. Previous studies have shown that wells sometimes contain heavy metals above the accepted standard for drinking water quality (Chowdhury, *et al.,* 2016). The ground water contamination analysis was carried out by taking samples of water from 13 wells in the study area during the month of August 2017. The metals that were analyzed include Lead (Pb), Zinc (Zn), Chromium (Cr) and Copper (Cu). The analysis was carried out to compare the experimental results with the contamination vulnerability index levels as shown by the overall vulnerability map prepared using the DRASTIC L model. The test was performed at the University of Lagos Central Research Laboratory where they were analyzed for metals with Atomic Absorption Spectrometer (AAS). Atomic Absorption Spectrometer is used for the quantitative determination of chemical elements using the absorption of optical radiation (light) by free atoms in the gaseous state. The technique is used for determining the concentration of a particular element (the analyte) in a sample to be analysed (Welz & Sperling 1999). Samples were preserved at 4oC and analysis was carried out within seven days of sample collection. Metal analysis was carried out by taking 50 ml of the water sample into a 250 ml conical flask, 10 ml of aqua regia was added and the mixture was evaporated on a hot plate in the fume cupboard to dryness. The sample was reconstituted with 25 ml of deionized water and filtered with a filter paper and funnel for AAS metal analysis.

The Nigerian Standard for Drinking Water Quality (NSDWQ) was approved by the Council of the Standards Organization of Nigeria in 2007. It specified the upper and lower limits of contaminants known to pose a risk to the wellbeing of individuals. It also provides a comparison of the World Health Organization's standard of water quality with that of the Nigerian Standard for Drinking Water Quality. Minor differences exist between World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ). [11].

Result

Vulnerability Result

The results of this study shows that out of the total area of 166.657 hectares, about 54.013 hectares were found to be within the low vulnerable zone with a DRASTIC index range between 101 - 123, about 52.225 hectares were observed to be in the moderately vulnerable zone with a DRASTIC index value ranging between 123 and 135 while about 60.417 hectares were in the high vulnerability zone with a DRASTIC index ranging between 135 and 154.

Statistical Analysis of the Vulnerability Map Result

Statistical analysis was performed on the DRASTIC L index produce for the vulnerability map, the result is stated on Table 3.

Table 3. A Statistical Summary of the DRASTIC L Parameter Maps

	D	R	A	S	T	I	C	L
Min	1	9	1	3	1	1	1	1
Max	10	9	6	3	10	1	6	10
Mean	5.5	9	3.5	3	6.25	1	3.5	5.5
SD	2.87	0	2.5	0	3.6	0	2.5	2.87
CV (100%)	52.18	0	71.42	0	57.6	0	57.6	52.18

Min = Minimum, Max = Maximum, SD = Standard Deviation, CV = Coefficient of Variation

A close observation of the statistical Table 3 shows that the coefficient of variations indicates that a high contribution to the variation of vulnerability index is made by aquifer media (71.42%), then topography and hydraulic conductivity (57.6%), Depth and distance contribution was (52.18%) while net recharge, soil media, impact of vadose zone, had no contribution to the variation of the vulnerability index.

Groundwater Contamination Analysis Result

The purpose of this analysis is to assess the relationship between the ground water vulnerability map and heavy metal concentration in the ground water. A total of thirteen hand-dug wells were sampled at increasing distances from the landfill site and analysed at Central Research Laboratory of the University of Lagos for the presence of heavy metals.

Table 4: A Statistical Summary of the Analysis Results

Description	Wells	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)	Cr (mg/L)
NSDWQ		1.00	0.01	3.0	0.05
WHO		2.00	0.01	NS	0.05
53, Olofin Street	(W1)	0.31	0.001	2.73	ND
4, Adesolarin Street	(W2)	0.13	ND	2.03	ND
23, Oremeji Street, Igando	(W3)	ND	ND	2.53	ND
14, Olorunsogo Street	(W4)	0.46	ND	2.53	ND
8, Kayode Onafinyin	(W5)	ND	ND	3.51	ND
38, Olofin Street	(W6)	0.12	ND	2.47	ND
8, Itoko Avenue	(W7)	0.03	ND	2.62	ND
52, Rafiu Odebiyi	(W8)	0.35	ND	2.71	ND
2, Rafiu Odebiyi	(W9)	0.63	ND	2.54	ND
2, Akandi Salisa	(W10)	0.40	ND	3.39	ND
54, Otunba Bamidele	(W11)	0.12	ND	2.05	ND
6, Alafia Street	(W12)	ND	ND	2.41	ND
Total filling Station	(W13)	0.58	ND	4.45	ND

Note. NSDWQ Values are the maximum permitted levels in the Nigerian Standards for Drinking Water Quality, ND- Not detected, NS- Not supplied. WHO values are the maximum permitted levels in the WHO Drinking Water Quality Guideline.

It can be seen from the result in Table 4 and Figure 4, that the concentration of Copper (Cu) was below the WHO and NSDWQ standard of 3.0 mg/L, However, wells 4, 9, l3 reported a higher concentration when compared to others.

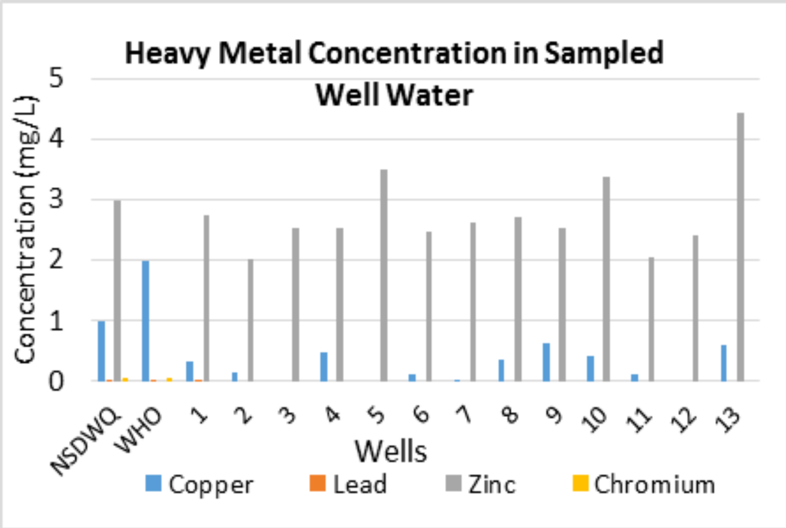

Figure 4. Heavy Metal Concentration in different Wells within the Study Area.

Lead (Pb) is regarded as a heavy metal, which can be poisonous to animals including humans. Lead is usually found in ore together with other metals including silver, copper, zinc and gold. Lead was only detected in well 1 and was not beyond WHO and NSDWQ standard (Table 4).

Zinc (Zn) is an essential mineral with exceptional biologic and public health importance. However, concentrations in humans above the optimum level can be toxic and can result in adverse biological effects. Zn was reported to be above the acceptable limit in well 5, 10, and 13 (Figure 4) of the study area; while others were within the acceptable limit. Chromium was tested for but was not found present in any of the wells sampled (Table 5).

Table 5. Descriptive Statistics of Metal Concentrations in Ground Water Samples

Parameter(mg/l)	**Mean**	**Standard Deviation**
Copper	0.313	0.2087
Lead	0.010	0.000
Zinc	2.766	0.660
Chromium	0.000	0.000

Discussion

In this research study, the DRASTIC L index was used to assess the hydrological vulnerability of landfill site in Alimosho Landfill Site area of Lagos in a GIS environment as also used by other researchers (Zhou, *et al.,* 1999; Afolayan, *et al.,* 2012). It was observed from the results of the statistical analysis that the mean for the recharge was 9. This value was the highest contribution to the vulnerability index, followed by topography with a mean value of 6.25. Depth and distance was 5.5, a moderate contribution to the vulnerability index, while aquifer and hydraulic conductivity contributed 3.5 to the vulnerability index. The lowest contribution was observed by the impact of vadose zone with a value of 1. The coefficient indicates that a high contribution to the variation of vulnerability index is made by aquifer media (71.42%), followed by topography and hydraulic conductivity (57.6%), Depth and distance contribution was (52.18%) while net recharge, soil media, impact of vadose zone, have no contribution to the variations of the vulnerability index. Findings from all these parameters agree with (Alaa & Ayser, 2014).

The area under study has a total coverage of 166.657 hectares out of which, about 54.013 hectares is in the low vulnerable zone with a DRASTIC index range between 101–123; about 52.225 hectares are in the moderately vulnerable zone with a DRASTIC index ranging between 123 and 135. About 60.417 hectares are in the high vulnerability zone with a DRASTIC index ranging between 135 and 154. The resultant vulnerability map was subdivided into three classes in relation to each degree of vulnerability according to the classification, this agrees with (Engel*, et al.,* 1996). It was discovered from the result that about 32.409% of the study area has low degree of vulnerability, while 31.339% of the area has moderate degree of vulnerability. About 36.252% of the study area is reported to be highly vulnerable and this is due to the landfill site.

It was observed that wells 15, 10, 11, 14 and 2 are within the low vulnerable zone while wells 9, 4 and 3 are seen to be within the moderate vulnerable zone. Wells 13, 12, 8, 7, 6, 5 and 1 are reported to be located in the highly vulnerable zone.

Findings from this study have shown that there seems to be some relationship between the location of these wells and the test results of the water analysis. Certain physical parameters like taste, colour and odour can serve as main indicators for assessing the quality of drinking water. It can also serve as indicators of water pollution, without taking into consideration other physical, chemical and biological variables of water. This research tested sampled underground water for presence of heavy metals. The results obtained agree with groundwater chemistry of the neighboring communities of Oregun, Ketu and Ojota, which were reported by (Oyeku & Eludoyin 2010). Copper (Cu) was not found to exceed the WHO and NSDWQ acceptable limit in all sampled wells, Although, wells 4, 9 and l3 had higher concentrations of 0.46 mg/L, 0.63 mg/L, and 0.58 mg/L respectively when compared to other wells.

Lead (Pb) was detected in Well 1 only with a concentration level of 0.001 mg/L and was not beyond WHO and NSDWQ limit, although its location is within the high vulnerable zone of map index result.

Zinc (Zn) was found to be beyond the NSDWQ acceptable limit of 3.0 mg/L in wells 5, 10, and 13. Well 5 (3.51mg/L) and 13 (4.45mg/L) are within the high vulnerable zone of the vulnerability map, however, well 10 (3.39mg/L) is not, rather it is located within the low vulnerable zone, yet the test result reported its concentration to be above the approved NSDWQ standard. Well 13 is located within a gas filling station and this may be reason it accounted for high level of Zn concentration.

Chromium (Cr) was not detected throughout in all the water samples tested in the study area.

Conclusion

This study has shown that landfill sites contaminate ground water and thereby compromise the quality of drinking water from wells in surrounding regions. Also, this study has shown that increasing distance from the landfill do not necessarily reduce the concentration of heavy metals presence in the wells as can be clearly seen in Well 10 which is located within a low vulnerable zone of the vulnerability map. It can be concluded therefore, that not all wells in the study area are within the acceptable WHO and NSDWQ standard for drinking water, hence a careful alternative is recommended.

Acknowledgments

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Plant Microbial Fuel Cells – Preliminary Experimental Data and Future Applications

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Abstract
Plant microbial fuel cells (P-MFC) are Bioelectrochemical systems (BESs) that convert chemical reactions naturally occurring between the rhizosphere region of a plant and bacteria into electricity. A P-MFC derives from a traditional Microbial fuel cell and is distinguished by its capacity to turn solar energy and organic substrates into bioelectricity, in-situ and without external input. Initially studied to be applied in wetlands, P-MFC can potentially be integrated in any vegetated area with low environmental risks, both for energy generation and water quality sensing. Currently the main factors limiting PMFC application are its low energy production and the cost of the materials used for the construction of the electrodes. This paper discusses the design of a configuration in which alternative materials derived from waste and organic sources are proposed for the electrode construction. An exhaustive overview of future PMFC applications and the challenges involved is introduced and discussed in detail.

Keywords: P-MFC, plants, recycled carbon felt, renewable energies

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Introduction

Energy poverty, borrowing the definition of Reddy is *"the absence of sufficient choice in accessing adequate, affordable, reliable high quality, safe and environmental benign energy services to support economic and human development"*(Reddy, 2000). The world's population that today lives in this state of poverty has no access neither to basic needs (cooking and heating), neither to services necessary for the individual and collective development (education, information, communication, etc.). In the absence of an adequate energy grid, biomass and oil-based fuels are employed to power small equipment and equipment for cooking. However, the use of these resources impose dangerous consequences for human health and the environment (González-Eguino, 2015).

The development of renewable energy resources will partly resolve these issues, providing more sustainable solutions. Nevertheless, studies have shown how the development of green energy is having large impact on the environment and biodiversity (Gibson, Wilman, & Laurance, 2017). Wind, solar, hydropower and bioenergy are low carbon emission technologies. However, these technologies may result in a more intensive land-use than traditional fuel energy and can be limited by geographical condition (hydropower and geothermal). Moreover, technologies such as solar and wind are still characterized by intense manufacturing processes and the disposal of their components in their end-of-life is still a problem.

This paper deals with a novel technology known as Plant Microbial fuel cell (P-MFC) (Timmers, 2012) using plants to generate continuous electricity, independently and without competing with soil used for agriculture. P-MFC is a renewable energy technology producing energy with low environmental impact, preserving food production and supporting the local economy and development (Nitisoravut & Regmi, 2017). However, technological and economic problems still limit its real application. Therefore, the aim of this work is to improve P-MFC sustainability (economic, social and environmental), and encourage an effective application of the system. The paper starts with the description of P-MFC operation and electrical performances are presented. Then, the study of a material is proposed, where attention is giving to the electrodes. Specifically, alternative materials for the electrode construction derived from recycled carbon fibre products and organic wastes are analysed. The main aim is to construct a cost effective and an energy efficient P-MFC.

1. P-MFC working principles and limiting factors

In a P-MFC two main structures are distinguished (Nitisoravut & Regmi, 2017): of bio-control, identified with the higher plants, and of bio-process represented by microbial population living in the rhizosphere. The role of the plant is to extract an organic matter production after receiving an external input i.e. the sunlight. The organic material produced and then released by the plant into the soil is degraded by electroactive material. During this oxidation process electrons are released. These electrons are then used to generate an electric current, through an external load, taking advantages of a difference in electrical potential. The principal steps occurring in a P-MFC system are photosynthesis, transport of organic matter to the anode compartment, anodic oxidation of organic matters by electrochemically active bacteria, and cathodic reduction of oxygen(Strik et al., 2011).

Through the photosynthesis process (1), plants extract the nutrients needed for their subsistence, converting the solar energy into glucose. During this phase approximately 100% of the light is absorbed by the plant. However, part of this (20-60%) is synthesized and then expelled as exudates into the soil (Wetser, 2016). This phenomenon is known as Rhizodeposition (Hartmann, Rothballer, & Schmid, 2008) and consist of the release of soluble sugar, organic acids, amino acids and hormones from living roots. These compounds are then degraded by the bacteria living in the rhizosphere, together with the macronutrients present into the soil. The growth of the bacteria is encouraged by the exudates themselves. By the breakdown of organic matter electrons and protons are released into the ground.

$$6CO_2 + 6H_2O \xrightarrow{Sunlight\ Energy} C_6H_{12}O_6 + 6O_2 \quad (1)$$

A P-MFC works based on this natural oxidation with a reduction phase, resulting in a redox reaction. During the redox process electrons are lost as a result of the substrates degradation, and then gained through the reduction of a chemical specie (oxygen). Using conductive materials it is possible intercept and extract this electric charge flow, thus generating an electric current in-situ and without external input (De Schamphelaire et al., 2008; Kaku, Yonezawa, Kodama, & Watanabe, 2008; Strik et al., 2011). A P-MFC takes advantages of the different chemical and physical conditions offered by the environment itself. Its configuration includes an anode integrated into the sediment where the plant grows (anaerobic condition). Here the soil operates as anodic chamber containing the organic substrates and oxidation phase. The soil also works as an electrical insulator isolating the anode from the cathode to be in touch. On the other hand, the cathode is exposed to the air (aerobic condition) where an adequate and constant oxygen delivery is guaranteed. In order to improve the oxygenation and the electrical conductivity of the material the cathode is usually put in wet condition.

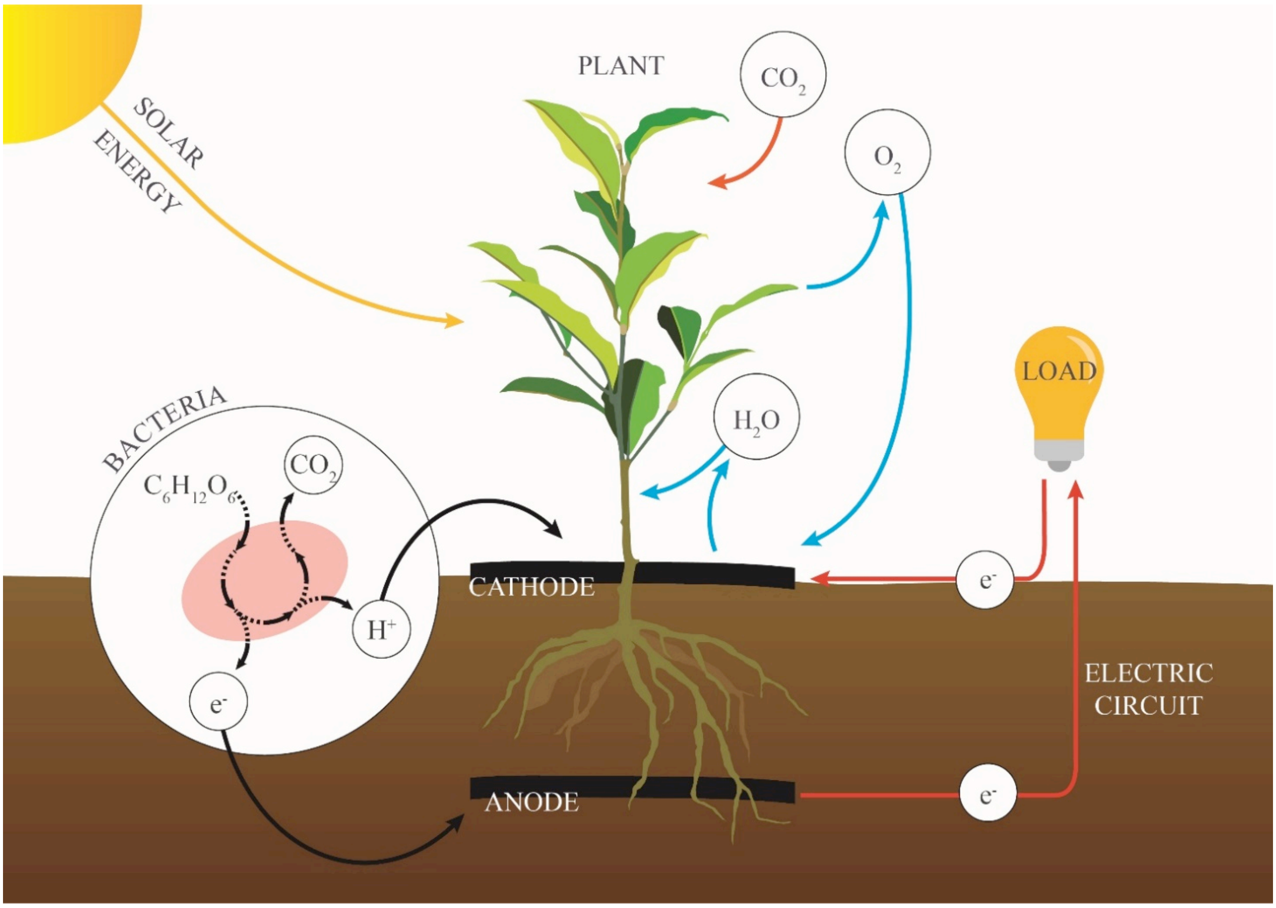

Figure 1 : P-MFC functioning scheme

The anode and the cathode are the negative and positive poles, respectively, of an electric circuit through which the electrical charges move driven by a potential difference. An oxidation reaction (at anode) and a reduction reaction (at cathode) take place supported by electroactive microorganisms (EAMs). These types of bacteria can directly transfer electrons to an electron acceptor such as the anode or the cathode. The formation of an electroactive biofilm (EAB) on the electrode surface can enhance the transfer of electrons by the improvement of the electrodes and bacteria interaction (Pentassuglia, Agostino, & Tommasi, 2017). Among the bacteria the most observed belong to the Geobacteracea family (Deng, Chen, & Zhao, 2012; Nitisoravut & Regmi, 2017; Strik et al., 2011). The presence of microorganisms driving the redox reaction and supporting the electricity generation has been observed both on the anodic and cathodic region.

P-MFC is a living system in which organic and inorganic components work together for electric current generation. However, the biological nature of the P-MFC is the main limitation to its performances. The success of the redox reaction depends on the microorganism behaviour which in turn is influenced by the capacity of the plant to release exudates. Again, exudation rate depends on the photosynthesis pathways. This interdependence means that the inefficiency of the bacteria or of the plant may affect the entire system. Hence, limiting the energy extraction.

Several factors affect a PMFC performance. Not all the plants are able to release the same exudate amount. Root morphology is a key factor together with plant age, soil quality, light intensity, nitrogen content into the soil and atmospheric CO_2 concentration (Wetser, 2016). Bacteria are sensitive to small changes. When the percentage of oxygen increases at the anode, the microorganisms present in the system can develop a metabolism characterized by a different electron transport. This can cause a reduction in the electrical current generation (Strik, Hamelers, Snel, & Buisman, 2008). Moreover, the size of the electrodes, their material and position must be take into consideration. For example, the proximity of the anode to the rhizosphere may affects the electrons harvesting(Wetser, 2016).

1.1 The influence of light intensity and photosynthetic pathways on exudates production

Light is the principal input for the photosynthesis process. The photosynthesis mechanism is used to convert solar energy into chemical energy and variation on light intensity and radiation field can affects plant activities. During photosynthesis, carbon is reduced from a simple form (CO_2) into sugar. Therefore, plant growth and reproduction depend on their ability to gain carbon. Plants can be distinguished into three categories according to their photosynthetic activity. Among plants typologies (C3, C4 and CAM), C4 plant type is the most appropriate to be employed for P-MFC tests thanks to their characteristics (Nitisoravut & Regmi, 2017). For example, their high rate of conversion of solar energy into bioelectricity, capacity to react very well under extreme dry and hot condition, and exhibition of a theoretical maximum limit photosynthesis efficiency of 6.0% against 4.6% of C3.

1.2 Catalysis of the redox reactions by electroactive bacteria

The percentage of exudates converted into bioelectricity depends on the redox reactions efficiency. In a BES system electron gain and loss may occurs with or without mediator (Wetser, 2016). In the first case, chemical reactions are simplified by introducing compounds such as thiamine, paraquat or methylene blue in the system (usually on electrode surface). However, despite the fact that these techniques may increase the energy output, the high toxicity of the compounds is extremely dangerous, especially for P-MFC set in environmental areas. Therefore, the use of microorganisms as catalysts is encouraged. The presence of microorganisms driving the redox process entail different advantages. The resulting system is fully independent and capable of self-repair and maintenance. Chemical reactions do not represent a risk for the environment and the plant but can promote the growth of the latter. The use of local resources allows to reduce the technological costs and promote the system sustainability. The main limitation of using microorganisms as catalyst for the redox reaction is the instability of the microorganism behaviour itself. Moreover, microbial community also depends upon the plant species, soil quality (structure, texture and pH), nutrient and nitrogen availability. In the same way EAB formation is affected by biological, system design, operating and environmental parameters (Pentassuglia et al., 2017).

1.3 The characteristics of the electrodes affect P-MFC total energy generation

The electrodes of a P-MFC can be connected externally, through an electrical load to harvest energy. In most experimental cases, the P-MFC is externally connected to a resistance to get a measure of the energy produced by the P-MFC. The power generated by the P-MFC is given by the following equation:

$$P = V \times I$$

Where, P is the electrical power (W), V is the voltage (V) across the external load and I is the current (A) flowing through the external load. The voltage is measured using a voltmeter and the current is obtained using the ohm's law:

$$I = {}^{V}/_{R}$$

Where, R is the resistance (Ω) connected externally to the P-MFC, acting as the electrical load.

Voltage and current losses (Degrenne, 2012) affect the total energy generated by the system. Voltage drop can be a consequence of the activation drop. During this phase, bacteria capture fraction of energy content of substrate for their growth and maintenance, reducing the number of electrons released at the anode and destined to the power generation. Moreover, voltage drop can be caused due to the resistive nature of the electrodes used. Furthermore, current drop is observed when the anode is not the only electron acceptor used by bacteria for the substrates degradation. In this case, electrons can migrate to the cathode reacting with alternative electron acceptor. A low anode attraction can be noted also when the system is in Open Circuit Voltage (OCV). In this condition the anode does not attract the electrons and bacteria are more likely to select alternative electrons acceptors. Therefore, voltage and current are not constant but are dependent upon various parameters, resulting in a variable energy output of the P-MFC.

While bacteria drive redox reaction, the anode and the cathode host the oxidation and reduction phase allowing the electric charges flow. Electrodes materials must be characterized by a good electrical conductivity, strong biocompatibility, chemical stability, large surface area and high porosity. These properties of the material help to reduce the internal resistance of the system encouraging the colonization of the electrode's surfaces by the bacteria. Carbon-based material such as carbon powder, carbon fiber and carbon felt are commonly employed as electrode material (Logan, 2008).

1.4 Maximum Power Point and electric circuit efficiency

Timmers et al. estimated that a P-MFC can reach a peak power output of around 3.2 Wm^{-2}. In natural conditions, the effective harvesting value decreases to 1.6 Wm^{-2} (Timmers, 2012). However, the maximum power density reported in literature is 240 mWm^{-2} (Helder, Strik, Hamelers, & Buisman, 2012).

Plant types	Photo synthetic Pathway	Research goal	MFC fabrication		Growth medium/Substrate	Operating condition	Maximum Power density $mW \cdot m^{-2}$
			Anode	Cathode			
E. crassieps	C3	COD removal, electrode position	Graphite discs	Graphite discs	Domestic and fermented distillery wastewater	Miniature benthic system	224.93
G. maxima	C3	Microbial community analysis	Graphite granules	Graphite felt	Hoagland solution	Climate chamber	80
O. sativa	C3	Effect of electrode size	Graphite felt	Graphite felt	Soil	Rice field	80
P. setaceum	C4	Anode placement	Graphite plate	Graphite plate	Red soil	Ambient	163
S. anglica	C4	Design configuration	Graphite felt	Graphite felt	Growth medium	Climate chamber	240

Table 1: P-MFC best data in literature (Nitisoravut & Regmi, 2017)

Note

C4: 4-carbon molecule formation when carbon fixation for photosynthesis.
C3: 3-carbon organic intermediate molecule 3-phosphoglycerate when carbon fixation for photosynthesis.
Climate chamber: controlled atmospheric and weather conditions.
Ambient: uncontrolled atmospheric and weather conditions.

At present, the low energy output is the most critical issue in P-MFC applications, together with the high cost of production ($ 70m^{-3}) (Xia, Zhang, Pedrycz, Zhu, & Guo, 2018). Although, efforts have been done to define the role of the plant, soil, bacteria and electrodes in P-MFC, no specific studies have been done on the electronic component. However, in the literature, it is possible to identify a ~~particular~~ strategy adopted to increase P-MFC energy efficiency. This strategy consists of tracking the Maximum Power Point (MPP (Helder, 2012). This condition is reached when the external resistance imposed on the system is equal to the internal resistance of the system itself. The implementation of this technique is done using a control algorithm. Among the control methods, the most commonly used is the Perturb & Observe (P&O) (Degrenne, 2012). In P&O, a small voltage perturbation is applied to the system and the corresponding change in power produced is observed. If the power increases due to the perturbation, the system is perturbed in the same direction in the next cycle as well. If the perturbation results in a lower power, the system is perturbed in the opposite direction during the next cycle.

Employing a dynamic regulation of the voltage at which the power is extracted helps to achieve higher performances than those normally obtained using a fixed load resistance. Moreover, this method can positively affect the bacterial community, favouring the presence of electroactive bacteria on the electrodes and speeding up the start-up time for the electricity generation (Song et al., 2016). Nevertheless, the technique presents a limitation. Despite being easy to operate, dynamic regulation has problems related to oscillations that can affect the total energy output. Specifically, this problem occurs when the P-MFC voltage and current values are not fixed but decrease and increase constantly, making it difficult to detect the exact MPP. Another strategy adopted to run the system as close as possible to the MPP usually consists of setting the system at OCV and then recording the data. Subsequently, the information is processed by a Power Management Unit (PMU) that decides the optimal voltage level at which the energy should be extracted. When using this strategy, the energy is not extracted constantly but an open circuit and a close circuit condition alternate. Boost charger-based circuits are also employed to extract energy. These devices are able to increase the output voltage from a P-MFC. The energy obtained can then be stored in a capacitor and used to supply energy to an electric device (Piyare, Murphy, Tosato, & Brunelli, 2017). The boost charger must be characterized by a low quiescent current demand, while the capacitor must be able to store and provide enough energy to power the electric device.

2. Critical issues in improving P-MFC efficiency

Although the development of a proper PMU may help in increasing the energy output, getting a continuous and stable electrical energy output from a P-MFC still remains a challenge. As discussed above, exudate production changes over time according to light intensity and plant species and its conversion into bioelectricity depends on microbial community and soil characteristics. Moreover, the MPP technique presents two main limitations (Helder, 2012): firstly, there is a difficulty in the determination of the exact MPP. P-MFC is an unstable system thus, the MPP changes continuously. Therefore, referring to a single polarization curve for the MPP, in real-time, is not practical. Secondly, the overall impedance of the system produces a limitation on the energy output.

Furthermore, reduction in the cost of production of a P-MFC should also be taken into consideration. More specifically, it is important to reduce the cost of the electrodes. At present, carbon fiber cost is around $21.5/kg (Rao, G A, P, & Kumar V V, 2018). This cost is destined to decrease, thanks to the introduction of new production techniques together with the use of low-cost input materials (i.e. recycled carbon fiber). Therefore, one of the main challenges in improving P-MFCs could be the use of low cost materials without reducing its energy efficiency.

The aim of this paper is to investigate this possibility by introducing the study of a new configuration in which electrodes made of recycled carbon fiber are tested. What follows is the account of a preliminary study in which the performances of low cost electrodes are investigated and compared to traditional carbon electrodes.

2.1 Materials and Methods

All the experiments were performed in a controlled environment and begun with the setting-up of pots, for the plantation, made of glass with a volume of 20cm^3. In total seven pots were set-up. Three pots (A, B, C) were characterized by electrodes made of non-recycled carbon felt. The anodes had an area of 50 cm^2 while the cathodes had an area of 90 cm^2. Titanium wire (0.30mm - Resistive titanium wire Gr1), sown onto the electrodes, was used to provide electrical connections to the electrodes. In the remaining four pots (D, E, F, G), the electrodes were built with recycled carbon felt (CARBISO™ M 100% Recycled Nonwoven Mat TDS, ELG Carbon Fibre Ltd). The plants used for the experiment were of two types. For pots A, B and C Eleocharis palustris (C4), a perennial aquatic plant living in wetlands, was chosen. It is common in Europe, North America, northern and central Asia, and North Africa. The second type plant used for pots D, E, F and G was the Carex morrowi (C3), a perennial grass spread all over the world, particularly in marsh areas. It is resilient towards variations in temperature. In both cases, the plants were cut to reduce dimensions and were placed inside the pots, above the anodes. For the potting, a growth medium was employed (pH 7.0, electrical conductivity 0.6 dS/m and porosity 90% v/v).

The use of different plant species derived by the difficulty emerged on reproduce the adequate environment necessary to guarantee the plants welfare. Specifically, the Eleocharis palustris is a plant living along the banks of small lakes and ponds. The difficulty of recreating the same conditions led to a slow decline in the health of the plants. Subsequently, a different plant species was chosen, the Carrex. Like the Eleocharis, this plant is a perennial grass but, compared to the Eleocharis, it does not need to be watered often and can live indoor. Therefore, the ease of maintenance led to its choice.

Figure 2: P-MFC pots design. Eleocharis configuration (A) and Carex configuration (B)

2.2 Operations and Measurements

Data collection took place over a period of 202 days (22 days Eleocharis and 180 Carex). During this period of time, several tests were conducted to compare the performance of the recycled carbon felt compared to the non-recycled carbon felt. All the configurations were initially monitored in OCV condition. In this phase the data were continuously collected through an electronic setup consisting of an Analogic to Digital Converter (ADC) and a small single board computer (Rasberry PI3). After a stabilization period, the configurations were connected to a series of resistances for the MPP tests. During these tests external resistances were applied and changed manually, and the data were collected continuously by electronic setup mentioned earlier. For configurations A, B and C (Eleocharis) the resistance range varied from 8 kΩ to 1.1kΩ, while for configurations D, E, F and G (Carex) the resistance was varied from 10 kΩ to 2.2 kΩ. The resistances were changed every 24h so that the P-MFCs could achieve stable voltage values.

3. Results and discussion

The maximum energy density recorded during the tests was 1,1E+01 J/m^2 per day (pot C). Among the configurations designed with the electrodes made of recycled carbon felt, pot F was the one to reach the highest value with 4,2E+00 J/m^2 per day.

Electrode Material (anode and cathode)	Configuration	Voltage (mV)	Current (µA)	Resistance (kΩ)	Power Density (mW·m^{-2})
Plant-e Carbon felt	A	446	262	1.7	0.11
	B	403	191	2.1	0.07
	C	**459**	**270**	**1.7**	**0.12**
CARBISO™ M 100% Recycled Nonwoven Mat	D	356	75	4.7	0.02
	E	237	107	2.2	0.02
	F	**327**	**149**	**2.2**	**0.04**
	G	473	69	6.8	0.03

Table 2: Best recorded data from MPP tests

Note: m^2-anode surface 0,011m^2

The configurations designed with non-recycled carbon felt generated an average of 0.10 mW/m^2 ± 0.02 against the 0.02mW/m^2 ± 0.009 of recycled carbon felt configuration. Configuration C was able to generate a power density which was 71% more than that of configuration F. However, as can be seen in fig. 3 it is possible that the data of configuration F (tab.1) is not definitive. Specifically, it can be seen in the two graphs of figure 3 that the power density curve of configuration C, after reaching a peak (MPP) starts to decrease. However, in the power density curve of configuration F it is not possible to clearly establish if the point at ±0.04mW/m^2 and 149 µA is the MPP of the system. This uncertainty of the data in configuration F was due to the impossibility to continue the data collection, as a result of the plant death (day 180).

Generally, Plant-e carbon felt demonstrated a lower electrical resistivity (0.5 Ωcm) compared to CARBISO™ M 100% Recycled Nonwoven Mat (14 Ωcm), and the configurations designed with non-recycled carbon felt reached a higher performance (fig.3).

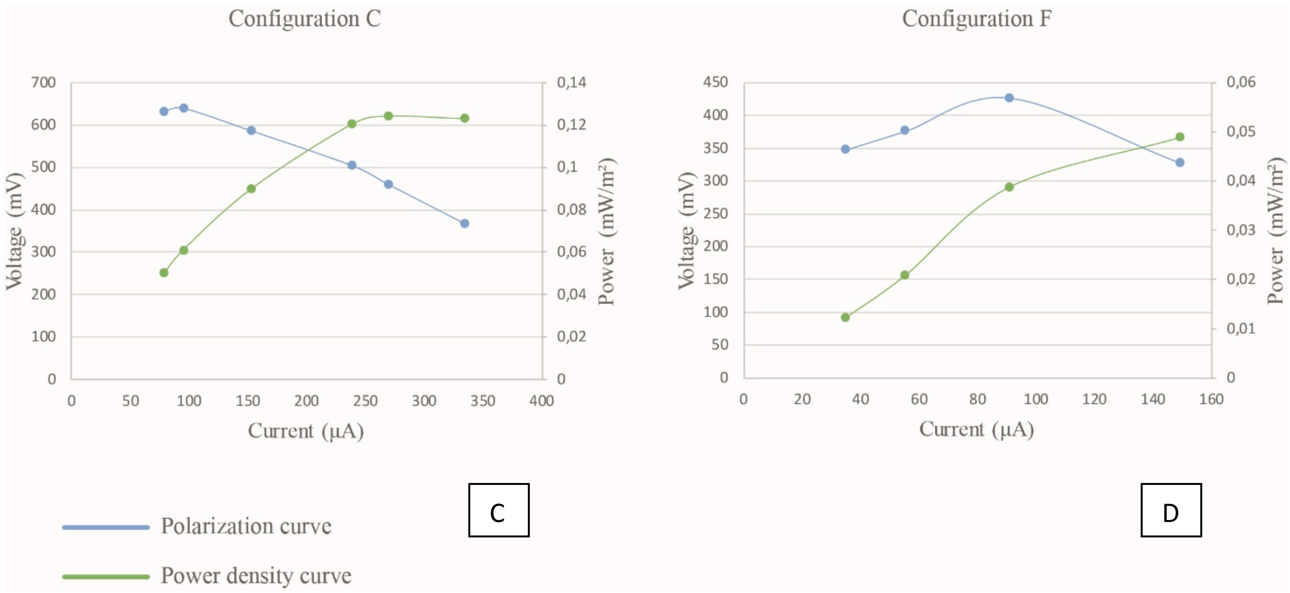

Figure 3: Maximum power point study of configurations C (fig.C) and F (fig.D)

Nevertheless, some considerations are necessary. During the tests different plants have been used. While the Eleocharis configurations were able to reach high voltage in a time period of 3 weeks, Carex configuration required around 25 weeks to reach similar values. On the other hand, Carex plants have a longer period of live than Eleocharis thanks to their easy maintenance. Eleocharis and Carex plants have a different photosynthetic pathway (respectively C4 and C3). This difference can affect the exudation productions and consequently the final energy generation. Therefore, reducing all types of limitations involved in the electric current generation in a P-MFC is fundamental in order to determine the potential of recycled carbon felt for electrodes' construction.

3.2 Electronic aspects need a deeper investigation

The design of an efficient PMU is fundamental for the improvement of P-MFC operation. P-MFC technology still produces a very low energy. Therefore, powering electronic devices may be quite difficult. Except for the work by Piyare et al. (Piyare et al., 2017), P-MFC studies do not consider the electronic aspect but mainly focus on the study of the microbial community, plant physiology and electrode conductivity. However, P-MFC efficiency principally resides on the capacity to use maximum amount of electrons present in the substrate to power an electric device with minimal losses.

3.3 Recycled carbon fiber may be used as electrodes

Another important limitation of P-MFC is the high cost of production compared to the low energy generation. Since P-MFC cost is strictly connected to the electrodes' material, P-MFC sustainability also depend on the selection of a material able to combine low cost with high performance. As shown above, carbon-based materials are commonly used for the electrodes' construction (Huong Le, Bechelany, & Cretin, 2017). However, carbon materials are characterized by high costs of production as well as a high environmental impact (Saburow et al., 2017). At the moment one of the main challenges is the development of low cost technologies through which recover carbon materials derived from EOL (end-of-life) products.

Figure 4 : CARBISO™ M 100% Recycled Nonwoven Mat. C) detail of the recycled nonwoven mat; D) the cathode used in recycled carbon felt configuration

In this paper the possibility to use recycled carbon materials for the electrodes' design is proposed. For the tests, the anodes of the configurations D, E, F and G were designed with recycled carbon felt.

Another material took into consideration and analysed in the literature (Bal Altuntaş, Akgül, Yanik, & Anik, 2017; Chacón, Cayuela, Roig, & Sánchez-Monedero, 2017; Huggins, Wang, Kearns, Jenkins, & Ren, 2014; Prévoteau, Ronsse, Cid, Boeckx, & Rabaey, 2016; Sophia Ayyappan, Bhalambaal, & Kumar, 2018) is the Biochar – a carbonised biomass obtained by the pyrolysis of vegetable waste. Biochar presents many benefits in plant welfare and exudates improvement compared to recycled carbon felt. When introduced in the ground, this material works as a soil improver guarantying high nutrients exchange and water retention. Moreover, thanks to its high surface area and porosity, EAB formation is encouraged. However, converting an organic source into an electroconductive material is a difficult and expensive process.

3.4 P-MFC design must not interfere with the plant growth and welfare

The presence of electrodes does not affect plant growth (Wetser, 2016). The death of the plants occurred after 22 days (Eleocharis) and 180 days (Carex). This can be related to other causes such as lack of nutrients, parasitic attack and waterlogging phenomenon. While in the first two cases, the administration of fertilizer and drugs can prevent such conditions, waterlogging problem depend on a deficiency in the design. Specifically, the absence of a drainage system in Carex configuration led to a water stagnation inside the pots with the consequent death of the plant roots. Providing a drainage system will not only prevent the waterlogging phenomenon but can also bring other advantages. While pure water is a poor electricity conductor, the presence of ions in the solution can transform the water in a good electricity conductor. Therefore, if anode and cathode are placed inside the same water in which there are ions (i.e. salt marsh), the solution may result in a short circuit. Well-drained soil can help reduce the water presence in the pot, preventing short circuit and minimizing the internal resistance due to the contact between the anode and the cathode. The recirculation of the water can also guarantee a fixed oxygen rate at the cathode stabilizing the reduction phase. A water solution enriched with organic matter, on the other hand, can promote oxidation phase at the anode guarantee a constant nutrient availability.

In addition to improving P-MFC design, it could be helpful to conduct tests in outdoor environments. In this way it can be easier recreate the environmental conditions specific to the nature of the plant used and study P-MFC behaviour in natural conditions.

4. Conclusions

Increasing energy output and reducing cost of production are the main challenges for the success of P-MFC. While the mechanisms guiding plant exudation and redox process are quite known, fewer efforts have been made on the development of electronic devices able to efficiently extract electrical energy from the system. Moreover, P-MFC sustainability and its ability to compete with traditional renewables technologies, depends on the identification of low cost solution for its design. The high production costs of P-MFC are strictly related to electrodes material. Proposals of alternative material must also consider the high performance, of the electrodes, required by the system. Recycled carbon fiber and biochar can be taken into account for electrode design, but additional studies are necessary. Further research should be conducted on the design of functional prototypes, studying their application in real contexts, and on alternative P-MFC applications such as waste water treatment and toxicity detection with a multidisciplinary approach.

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The Importance of the ISO9001 Certification on the Financial Results of Portuguese Pharmacies

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Abstract

In the last decades, quality management has become an essential tool for companies looking to gain sustainability and competitive advantage, and thus survive an increasingly competitive market. Portuguese pharmacies were no exception, and implemented mechanisms capable of boosting their financial and operational results. This work aims to study the relationship between the pharmacies certified by ISO 9000 and non-certified pharmacies, in the year 2015 in Portugal, and the impact that this certification caused on the financial results presented by these companies in the same year. In this study, the relationship between some financial ratios of Portuguese pharmacies (Return on Equity, Return on Used Capital, Profit Margin, Solvency Ratio and Liquidity Ratio) was analyzed through a Mann-Whitney econometric test, comparing the results with a sample of pharmacies that did not obtain certification by ISO 9000. Based on this study, it is concluded that in Portuguese pharmacies the existence of ISO 9000 certification is not relevant to the financial results since only on two variables, Return on Equity and Return on Capital used, there is a significant and positive difference. In the other variables studied, the existence, or not, of the certification has no influence on the results. Finally, it is also concluded that the variable Return on Equity is strongly influenced by the existence of the ISO certification, since this ratio oscillates strongly in the comparison between certified pharmacies versus non-certified pharmacies.

Keywords: Pharmacies, ISO9000, Sustainability, Performance, Quality Management, Financial Results.

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Introduction

Since the 1950's companies have been increasingly concerned about quality management. According to Martínez-Costa and Martínez-Lorente (2007), quality management clearly contributes to increase customer satisfaction and trust. On the other hand, the introduction of quality standards and processes enables a reduction of internal costs, an increase in productivity and a continuous improvement in image and processes, and it also allows easy access to new markets (Gotzamani, Theodorakioglou & Tsiotras, 2006). In this context, quality management is a strategic and competitive factor, since it allows evaluating the conformities determined by the organization for its products and/or services, through internal processes, guaranteeing the client a product designed according to standards, procedures and norms that are quite well defined and delineated.

Also according to Soares (2014), quality comes as a motor for a strategy focused on the client, which will meet their explicit and implicit expectations, while increasing productivity.

Quality certification is a visible face of quality management. The ISO 9001 norm belongs to the ISO 9000 family and is characterized by an extensive set of requirements standards, guidelines and other supporting documents that, together, can provide users with a set of tools with which they can manage and improve their organizations.

The International Organization for Standardization (ISO) is formed by a Technical Committee that develops a universal set of accepted norms in the field of quality. This Committee started its work in 1989 and the number of companies adopting this set of requirements has grown exponentially. The ISO 9000 norms set originally published in 1987 has since undergone two improvement cycles, including a smaller revision in 1994 and a deeper modification in 2000. However, certification according to the ISO 9001 norm refers to the Quality Management Systems (QMS) implemented in the company and not to the intrinsic quality of the products and services provided to customers, for which there are other certification processes.

According to Pinar and Ozgur (2007), ISO 9001 is the world's largest voluntary standard for companies and governments. The number of ISO 9001 norm certifications has increased exponentially on a global scale. In 2009, the number of certificates issued by the ISO 9001 standard was 1.064.785 distributed by 178 different countries according to the Certified Companies Guide 2010/2011. In 2009, Europe accounted for 46.53% of the world's share of certifications, with a relative decrease in the world's market share compared with 2005 (49.10%) (Certified Companies Guide, 2013). These values reveal the importance of this norm, mainly in the European continent, with Portugal having 0.47% of the world's quota, the lowest value in the last 5 years.

Quality management aims ultimately to create value for shareholders and customers. Therefore, the literature presents several empirical studies that analyze the implications of quality management upon organizational performance (Beirão & Sarsfield-Cabral, 2002; Nicolau & Sellers, 2002; Martínez-Costa & Martínez-Lorente, 2007). Those studies have been developed over many sectors (e.g.: hospitality, manufacturing) and in different countries such as Spain, Japan, Italy, the United States and New Zealand.

This empirical study aims to analyze the relationship between quality certification and the financial performance of Portuguese pharmacies. In the literature, no studies analyzing this sector were found. Pharmacies are mostly small companies, with an average of 5.7 employees, and reflect the permanent effort of the sector in the modernization of the infrastructures that they put at the service of the population.

Thus, certification by ISO 9001 is a relatively recent event in the pharmaceutical sector in Portugal. Of a total of 2.670 pharmacies only 54 were certified in the year under study. Thus, this paper seeks to contribute to a better knowledge about a topic that has received attention from the international academic community in other sectors.

Literature review and research questions

The adoption of a Quality Management System (QMS) is based on the need for companies to improve their competitiveness and create value for shareholders and customers. According to Kartha (2004) organizations have realized that the key to increase productivity and profitability is to improve quality and thus survive the competition. Companies are forced to return to the fundamentals of quality improvement management and cost competitiveness tailored to their products and / or services.

In the same line of thinking, Jitpaiboon and Rao (2007) point out that the globalization of the market, the high level of competition between companies, and the more demanding requirements established by clients, are among the most critical factors that influence and stimulate a company to implement a modern and effective Quality Management System.

Also Soares (2003) considers that the most relevant trends for the future are the increase of Quality in service companies, due to the increasing weight of services in the current economy.

The ISO 9000 norm family is an instrument for companies to start a process of implementing a QMS (Jitpaiboon & Rao, 2007). ISO has developed a set of quality requirements as a model for quality assurance in the project, production, installation and service, thus serving as a tool for the beginning of the implementation of such a system. For many companies, ISO 9000 are the starting point of a system that guarantees the quality of their products and/or services.

Also according to Magd and Nabulsi (2012), companies certified by ISO 9001 reveal a willingness to adopt the principles of a management model according to total quality. But regardless of all the efforts and research projects already undertaken under the ISO 9001 norm, results that are significantly contradictory and unanswered questions, still remain (Sampaio, Saraiva & Rodrigues, 2009).

The literature presents a large number of empirical studies that analyze the impact of QMS on company performance (Dannu & Ayokanmbi, 2008; Feng, Terziovski &

Samson, 2008; Pinar & Ozgur, 2007; Saizarbitoria & Landíni, 2006). The meta-analysis works developed by Jitpaiboon and Rao (2007) and Claver-Cortés, Molina-Azorín, Pereira-Moliner and López-Gamero (2007) present a synthesis of the studies on the subject. In general, the results of the meta-analysis of these two studies do not show the unequivocal existence of a positive relationship between the adoption of QMS and business performance. This fact extends to the effect of ISO 9001 on the performance of companies (Lafuente, Bayo-Moriones & García-Cestona, 2009). Depending on the author and the country under study, different conclusions are reached about the impact of the norm.

According to Beirão and Sarsfield-Cabral (2002) and Nicolau and Sellers (2002), there is a positive effect on the stock market in the United States, Portugal and Spain after certification. Nevertheless, Martínez-Costa and Martínez-Lorente (2003) state that there is no relationship between the stock market and certification in the Spanish market. In turn, Aarts and Vos (2001) indicate that there is a negative relationship between the results presented and ISO 9000 certification in New Zealand. There are also other authors (Gotzamani et al., 2006), stating that the implementation of this norm leads to a number of benefits:

- improvements in the internal and operational organization of companies;
- improvements in internal and external communication;
- employees that are more aware about the importance of quality;
- improvements in the quality of the goods produced and services provided;
- the reduction of quality costs;
- and, lastly, a greater consumer satisfaction and increased confidence in products.

On the other hand, there are other perspectives that are less optimistic concerning the results of implementing this set of standards. For example, Corrigan (1994) and Henkoff (1993) indicate that certification makes processes more bureaucratic, less flexible and reduces innovation. This view is partly shared by Stephens (1997) who states that the outcome after certification also depends on a continuous system of quality guarantee that is adaptable to external changes.

Another factor that strongly influences the success or failure of certification is the willingness to implement it correctly. According to Gotzamani et al. (2006), the maximum benefits of ISO 9001 certification are achieved when certification motivations are internal and true, that is, when they are part of a global strategy of the company.

Moreover, much of this willingness has to start from the top managers, and how they transmit it to the remaining employees. Therefore, the ISO 9001 norm should not be used only as a marketing tool or as a promotional action for the company, but rather as a way to achieve excellence (Jitpaiboon & Rao, 2007).

We can thus conclude that the existence of a QMS is positive for the performance of companies, as it contributes to continuous improvements in operational processes, documentation processes, increase in customer satisfaction, and a reduction in the number of errors. However, it should be noticed that, according to some authors, it is not consensual that the ISO 9001 norm is the best way to start a quality guarantee process.

Research questions

Pharmacies play an extremely important social role because they are part of a key sector for the well-being of citizens. Therefore, the improvement in the quality of the services provided may have very positive effects on the clients and investors of pharmacies.

The purpose of this analysis is to understand whether certification has a positive impact upon the financial results, and on which of these results the impact is most significant, helping us to understand how the ISO 9001 norm has an impact on the financial results of pharmacies.

This analysis will also be helpful in understanding where it is possible to improved, and where to invest at the time a pharmacy decides to implement the ISO 9001 certification, or opt for another quality management system.

Therefore, this study aims essentially to answer two research questions:

- Do companies certified by ISO 9001 in the pharmaceutical sector in Portugal obtain better financial results than non-certified companies do?

- Which indicators under study are the most susceptible to ISO 9001 certification?

In order to be able to answer these two questions, an econometric Mann-Whitney test will be applied, which will allow to assess the importance of certification by the ISO 9001 norm, by comparing the results of the certified sample with those of the control group, which corresponds to a set of non- certified pharmacies.

Methodology

The methodology used in this research is bibliographic and exploratory. The research is a bibliographical one because we used existing empirical studies about the impact of quality management systems on the performance of companies to our theoretical framework. This study is also exploratory because there are no studies on the impact of ISO 9001 upon Portuguese pharmacies.

The study focuses on Portuguese pharmacies that are certified by ISO 9001 and other non-certified pharmacies. The selection of the sample followed the following steps. In a first phase, starting from the Guide of Certified Companies of *Jornal de Negócios*, we verified that there were 54 pharmacies certified by the ISO 9001 norm at the end of the year under study.

However, the sample of this study considers only 30 certified pharmacies, as the remaining 24 pharmacies are sole proprietorships whose data are not considered in the databases that were used, or are recent pharmacies that do not have data available. The control sample of non-certified pharmacies consists of 90 pharmacies that were randomly selected.

The second stage consisted of the collection of the financial data through the database SABI (*Sistema de Análisis de Balances Ibéricos*), and through data provided by Informa D&B. Finally, the software used to carry out this study was the Statistical Package for the Social Sciences (SPSS).

In order to test the research hypothesis, the Mann-Whitney econometric test was used to verify if the level of performance among certified pharmacies is different from the performance of the control group of non-certified pharmacies.

The performance evaluation focused on the following financial indicators:

- Return on Equity is an indicator of the performance of the capital invested in the company by the shareholders/partners. The Return on Equity determines the attraction of potential investors in the long term;

- Return on Used Capital expresses the result of a company based on the used capital. Demonstrates the company's ability, through its production process, to generate value for investors in general;

- Profit Margin corresponds to the difference between total costs (fixed and variable) and the price that the consumer pays for the final product;

- Solvency Ratio demonstrates the proportion of company assets that are financed by equity capital against the proportion of third-party capital. The higher the value of the ratio, the more financially stable the organization is;

- Liquidity Ratio corresponds to the financial capacity of the company to meet its short-term liabilities, thus being a short-term solvency ratio.

Results analysis and discussion

The main objective of this study is to quantify the impact of the ISO 9000 certification on the financial results of pharmacies in Portugal in the year 2015, based on the comparison of the results of pharmacies that did not obtain this same certification.

Taking into account the population of pharmacies certified by the ISO 9001 norm in Portugal, of the approximately 2700 existing pharmacies, only around 2% of them are certified, from where we conclude that only a small number of pharmacies is certified.

Table 1 shows the descriptive statistics of financial performance variables. In general, the results show a large difference in Return on Equity and Return on Capital Used between the two samples, with the companies certified by ISO 9001 having better results than non-certified pharmacies.

The other three variables under study have identical results between the two samples, with the highest values occurring for the pharmacies without the ISO 9001 certification.

	Return on Equity	Return on Used Capital	Profit Margin	Solvency Ratio	Liquidity Ratio
Means					
Certified	21,45	24,06	4,93	50,52	1,44
Non-Certified	5,77	12,21	5,38	51,66	2,17
Standard deviation					
Certified	25,53	27,71	11,92	26,19	1,52
Non-Certified	39,42	26,44	10,32	25,68	4,42

Table 1 - Descriptive Statistics of Financial Performance
Source: Authors

The Mann-Whitney test with $\alpha = 0.05$ was used to verify differences between certified and non-certified pharmacies. The test consists of a non-parametric test alternative to the t-Student test (because it is not possible to say with certainty that the sample was withdrawn from a population with a normal distribution) to compare the means of two independent samples. The Mann-Whitney test statistic can be defined as:

$$U_a = n_a n_b + \frac{n_a(n_a+1)}{2} - \sum R_a$$

and

$$U_b = n_a n_b + \frac{n_b(n_b+1)}{2} - \sum R_b$$

Table 2 shows the non-parametric test results, which point to a difference in the performance of certified and non-certified pharmacies, with the exception being the Solvency Ratio. For the variables Return on Equity, Return on Used Capital and Profit Margin, certified pharmacies perform better than pharmacies that are not certified by ISO 9001.

In the case of the Solvency Ratio the case is slightly different. The two samples have identical distributions (59,18 and 60,14) and the 'p' assumes the, rather high, value of 0,811. For the Solvency Ratio the conclusion is that we cannot reject the hypothesis of equality of performance between the two samples.

Finally, the Liquidity Ratio variable shows a behavior that indicates that non-certified pharmacies perform better than certified pharmacies.

In summary, the results suggest that there is a global difference in performance between the two samples of pharmacies under study, and in most cases the pharmacies that obtained the ISO 9001 certification have better average results than those who did not obtain the same certification.

	Mean Certified pharmacies	Mean Non-Certified pharmacies	Test Statistic	p-value
Return on Equity	74,20	55,93	939,00	0,013
Return on Used Capital	73,80	56,07	951,00	0,016
Profit Margin	70,87	56,34	1009,00	0,046
Solvency Ratio	59,18	60,94	1310,50	0,811
Liquidity ratio	48,25	64,58	982,50	0,026

Table 2 - Mann-Whitney test results
Source: Authors

Conclusions and recommendations

The existence of quality concerns is in many cases seen as a way for companies to obtain greater performance results. However, it is not certain that certification by ISO 9001 brings better results to certified organizations relative to those that choose not to certify.

It was the objective of this study to give a new perspective on the impact of ISO 9001 certification on the financial performance of pharmacies in Portugal in the year 2015 and thus to add a new contribution, supported by the application of different methodologies to two different samples.

Firstly, a simple averages analysis was performed (Table 1), comparing the averages of the certified pharmacies with the averages of the non-certified ones, and it was concluded that the certified pharmacies obtained better results in the Return on Equity and Return on Used Capital, and worse results in the other three variables under study.

These results appear contradictory as certified pharmacies have better Return on Equity, but then, on average, their Profit Margin, Solvency Ratio and Liquidity Ratio are worse. However, it should be noted that the difference obtained in any of these indicators, although higher in non-certified pharmacies, is very close to that obtained by certified pharmacies, which is not the case in the other two indicators, where the variation is quite high. Regarding this aspect, we have to take into account that we are analyzing only five indicators, and in the day-to-day business, there are a multiplicity of factors and variables that influence the results, which could not be taken into account.

Because in this first analysis it is not possible to draw a fully valid conclusion about the impact of quality standards upon financial results of these two samples, a Mann-Whitney statistical test was then carried out. Its main goal was to understand if any of the variables under analysis is influenced or not by the existence of the ISO 9001 certification.

We will now answer Question 1 of this study - Do companies certified by ISO 9001 in the pharmaceutical sector in Portugal obtain better financial results than non-certified companies do? - concluding that in the Portuguese pharmacies, in the year 2015, the existence of ISO 9001 certification is not relevant to the financial results. Only on two of the considered indicators, Return on Equity and Return on Capital Used, there is a significant and positive difference, whereas in the other indicators the existence, or not, of certification has no influence on results.

Regarding Question 2 - Which indicators are the most susceptible to certification by ISO 9001? - we can say that only the variable Return on Equity is strongly influenced by the existence of certification, as this ratio changes considerable in the comparison of certified versus non-certified pharmacies.

In short, it can be concluded that ISO 9001 does not have a significant relevance in the financial results of Portuguese pharmacies. However, it should be taken into account that when talking about pharmacies we are essentially referring to a place that sells products equal to those sold in other pharmacies. Most people usually opt for one or another pharmacy based on factors such as location and proximity to their home or workplace, rather than actually motivated by the quality of the service.

Concerning this study, it is also necessary to take into account some limitations, such as not analyzing whether the pharmacies considered as non–certified in the sample chose to adopt the ISO certification only partially, or if they are certified by other quality systems.

The main difficulties of this study were the collection of data, since most pharmacies are sole proprietorships and therefore do not have to submit financial data. It was also difficult to perceived understand the date of certification of each of the pharmacies that adopted the certification, so that a longitudinal analysis could be made.

This study addresses the impact of ISO 9001 certification on the performance of pharmacies in Portugal, in order to produce an empirical study of a subject as complex as the relevance of quality management in companies’ results. Being this such a vast subject it cannot be said that it has been advanced to exhaustion.

Therefore, it is suggested the study of the impact of not only the certification by the ISO norm but also by other quality systems.

For future work, a similar study may be carried out in other sectors, taking into account different indicators, in particular some that are not only financial, but also operational.

Another recommendation consists of performing a temporal analysis, that is, not to analyze the results of a single year, but to check the evolution of results over a given period. For this type of study, the period under analysis varies according to the studies carried out and the authors consulted.

For example, Corbett, Montes-Sancho and Kirsch (2005) consider a 10-year period, whereas Heras, Dick and Casadesús (2002) consider 5 years, and Martínez-Costa and Martínez-Lorente (2007) consider a 3 years period, reflecting this temporal difference, the different perception of time horizon of each author, in relation to the impact of certification upon results.

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Transient Flow Modelling of the Impact of CO_2 Stream Impurities During Geological Sequestration

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Abstract

Following the quest for energy sustainability and cleaner environment, Carbon Capture and Storage (CCS) is expected to play a significant role in reducing carbon dioxide (CO_2) emissions. Outlining the impact of impurities (such as O_2, N_2, H_2O, H_2S, Ar, SO_x, NO_x, Hg etc.) in the gas or dense phase CO_2 stream arising from fossil fuel power plants, or large scale industrial emitters, is of fundamental importance to the safe and economic injection of the captured CO_2. This study investigates the impact of varying range of impurities expected from the main CO_2 capture technologies used with fossil-fuelled power plants on the pressure and temperature profiles during CO_2 sequestration. The analysis presented is with respect to the range of impurities present in CO_2 streams captured using pre-combustion, post-combustion and oxy-fuel technologies. Given the possibility of rapid, quasi-adiabatic Joule-Thomson expansion when high pressure CO_2 is injected into a low pressure injection well, which may lead to significant temperature drops posing several risks, including: blockage due to hydrate and ice formation with the formation water in the perforations at the near well zone; thermal stress shocking of the wellbore casing steel leading to its fracture and ultimate escape of CO_2. Therefore, in this study we investigate the time-dependent behaviour of the CO_2 stream at the wellhead and perform an analysis on varying CO_2 stream impurities combination.

Keywords: CO_2 injection, CO_2 stream, impurities, ramp-up

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Introduction

Carbon capture and geological storage represents an option that could play a prominent role in reducing anthropogenic CO_2 emissions into the atmosphere, comparable in size with improving energy efficiency and energy conservation. The principle is quite simple: capture CO_2 from large sources before it would be vented into the atmosphere, transport it to a storage site, usually by pipeline but also by ship where warranted, and inject it at least several hundreds of meters deep below the ground surface if onshore, or below the seabed if offshore. Geological media suitable for CO_2 storage must have the necessary capacity to store the intended volumes of CO_2, must have the injectivity needed to take in the CO_2 at the rate that it is supplied, and must confine the CO_2 to the storage site and impede its lateral migration and/or vertical leakage to other strata, shallow potable groundwater, soils and/or atmosphere. Such geological media are oil and gas reservoirs and deep saline aquifers that are found in sedimentary basins.

Impurities in the CO_2 stream have the potential to affect the efficiency and safety of the storage systems. For instance, the presence of impurities may increase risks associated with corrosion and alter the phase behaviour of the CO_2 stream. The presence of impurities is likely to have a significant effect on the phase behaviour, with implications for the design and operation of pipelines and injection wells. The presence of impurities could also pose a significant threat of increased corrosion of pipeline and well materials. Impurities in CO_2 captured from combustion based power generation with CCS can arise in a number of ways. Water is a major combustion product and is considered an impurity in the CO_2 stream. The elements inherently present in a fuel such as coal include sulphur, chlorine and mercury, and are released upon complete or incomplete combustion and form compounds in the gas phase which may remain to some extent as impurities in the CO_2 after it is captured and compressed. The oxidising agent used for combustion such as air may result in residual impurities of N_2, O_2 and Ar (Porter et al, 2015).

Literatures on CO_2 stream impurities

Several literatures (Alex, 2016; Hajiw et al, 2018; IEAGHG, 2011; Mahgerefteh et al, 2012; Wang et al, 2011; Wang et al, 2015; Wetenhall et al, 2014) on the effects of CO_2 stream impurities are available and mostly focussed on the rate of CO_2 injectivity, phase behaviour, storage capacity, transportation, compression and pipeline. Wang et al, (2011) developed a simple formula to enable quick determination of the effects of impurities in CO_2 streams on geological storage. The study highlighted that non-condensable impurities such as N_2, O_2 and Ar greatly reduce CO_2 storage capacity of geological formations, and there is a maximum reduction of the storage capacity at a certain pressure under a given temperature. Their revealed that impurities which are more condensable than CO_2, such as SO_2, can increase the storage capacity, and there is a maximum increase at a certain pressure under a given temperature; change of density caused by non-condensable gas impurities results in lower injectivity of impure CO_2 into geological formations. The importance of CO_2 impurities on the range of operation, safety considerations, fracture, cracking, corrosion control, dispersion in the event of a release, fluid density, operating pressure and temperature and the quantity of CO_2 that can be transported was studied by Wetenhall et al., (2014). The study summarises the “impact of CO_2

impurity on CO_2 compression, liquefaction and transportation” following various capture technologies. Porter et al., (2015) studied CO_2 purification technologies available for the removal of CO_2 impurities from raw oxy-fuel flue gas, such as Hg and non-condensable compounds. They concluded over 99% CO_2 purity levels are achievable using post-combustion capture technologies with low levels of the main impurities of such as N_2, Ar and O_2. However, CO_2 capture from oxy-fuel combustion and integrated gasification combined cycle power plants will need to take into consideration the removal of non-condensable acid gas species, and other contaminants. The actual level of CO_2 purity required will be dictated by a combination of transport and storage requirements, and process economics.

This paper addresses the fundamentally important issues surrounding the impact of typical CO_2 impurities in the injection of gas or dense phase CO_2 stream from fossil fuel power plants and other industries fitted with carbon capture and storage (CCS) technologies, upon the safe and economic transportation of CO_2 mixture. Understandably, the ultimate composition of the CO_2 stream captured from fossil fuel power plants or other CO_2 intensive industries and transported to a storage site using high pressure pipelines will be governed by safety, environmental and economic considerations. This study investigates the impact of varying range of impurities expected from the main CO_2 capture technologies used with fossil-fuelled power plants on the pressure and temperature profiles during CO_2 sequestration. The analysis presented is with respect to the range of impurities present in CO_2 streams captured using pre-combustion, post-combustion and oxy-fuel technologies.

Before the steady injection of CO_2 into the reservoir can be started, it is necessary to perform time-dependent operations to estimate important reservoir properties, e.g. permeability and pressure. Such operations include start-up, shut-in and emergency shut-down, which prove to be critical in the overall design of the well (Böser & Belfroid, 2013). Even after steady injection conditions are reached the well may be shut in and started up for maintenance of the upstream transportation system or other routine checks. It is therefore of paramount importance to be able to predict the behaviour of the CO_2, in terms of pressure and temperature along the full length of the well, to characterise and quantify potential risks (Li, *et al*, 2015).

Figure 1 shows a schematic diagram of an ideal CO_2 injection well. From the top of the injection well to the reservoir the CO_2 is affected by several physical effects that contribute to the pressure and temperature profile along the well. Heat will be exchanged with the surrounding rocks along the well. This will not only affect the fluid properties of the CO_2 in the well but also the rock will be cooled or heated by the fluid flow.

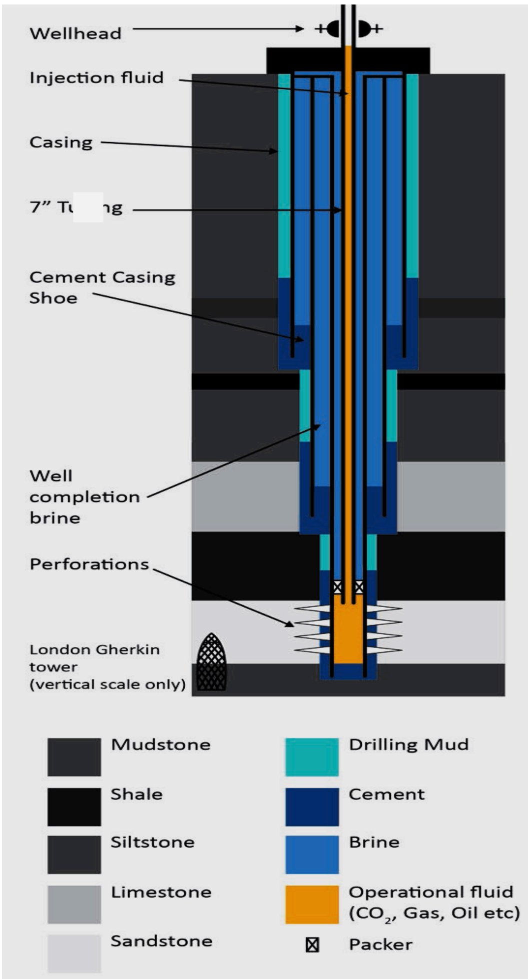

Figure 1: CO_2 injection well (Pale Blue Dot Energy, 2016)

This study is focused on modelling the transient flow behaviour of carbon dioxide (CO_2) stream with impurities during geological sequestration. Injecting a highly-pressurised CO_2 into a formation with lower pressure will induce a rapid quasi-adiabatic Joule-Thomson expansion effect. As such, the resulting effect on the formation may be:

- Blockage due hydrate and ice formation with interstitial water around the wellbore and
- Thermal shocking of the wellbore casing steel, leading to its fracture and ultimately escape of CO_2.

The model and fluid dynamics

Fig. 2 shows a schematic flow diagram of an injection tube. A control volume of a section of the tube is considered for analysis and derivation of model governing equations.

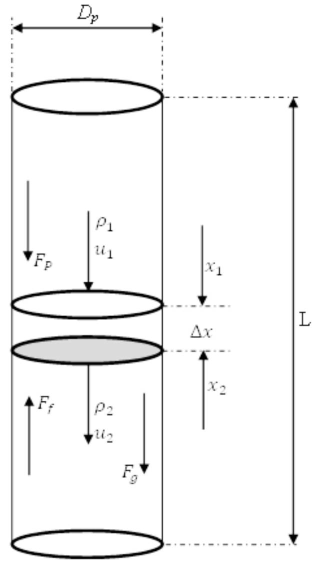

Fig. 2: Schematic representation of a control volume within a vertical pipe and the forces acting on it

Where F_p, F_f, F_g, ρ and u are pressure force, frictional force, gravitational force, fluid density and velocity respectively. L, D_p and Δx are well depth, diameter and differential control volume.

This study considers a purely vertical injection tube only hence, pipe inclination is unaccounted for. The following simplified assumptions are applied:

- One-dimensional flow in the pipe
- Homogeneous equilibrium fluid flow
- Negligible fluid structure interaction through vibrations
- Constant cross section area of pipe

The assumption of homogeneous equilibrium flow means that all phases are at mechanical and thermal equilibrium (i.e. phases are flowing with same velocity and temperature) hence the three conservation equations should be applied for the fluid mixture. Although, in practice usually the vapour phase travels faster than the liquid phase, the HEM model has been investigated proven to have an acceptable accuracy in many practical applications.

The following gives a detailed account of the homogeneous equilibrium model employed for the simulation of the time-dependent flow of CO_2 in injection wells. The system of four partial differential equations for the CO_2 liquid/gas mixture, to be solved in the well tubing, can be written in the well-known conservative form as follows:

$$\frac{\partial}{\partial t}\boldsymbol{Q} + \frac{\partial}{\partial x}\boldsymbol{F}(\boldsymbol{UQ}) = \boldsymbol{S}_1 + \boldsymbol{S}_2 \quad (1)$$

where

$$\boldsymbol{Q} = \begin{pmatrix} \rho A \\ \rho u A \\ \rho E A \\ A \end{pmatrix}, \quad \boldsymbol{F}(\boldsymbol{Q}) = \begin{pmatrix} \rho u A \\ \rho u^2 A + AP \\ \rho u H A \\ 0 \end{pmatrix}, \quad \boldsymbol{S}_1 = \begin{pmatrix} 0 \\ P\frac{\partial A}{\partial x} \\ 0 \\ 0 \end{pmatrix}, \quad \boldsymbol{S}_2 = \begin{pmatrix} 0 \\ A(F + \rho\beta g \\ A(Fu + \rho u\beta g \\ 0 \end{pmatrix} \quad (2)$$

In the above, the first three equations correspond to mass, momentum, and energy conservation, respectively. The fourth equation describes the fact that the cross-sectional area A is, at any location along the well, constant in time, but might vary along the depth of the well. Moreover, u and ρ are the mixture velocity and density, respectively. P is the mixture pressure, while E and H represent the specific total energy and total enthalpy of the mixture, respectively. They are defined as:

$$E = e + \frac{1}{2}u^2 \quad (3)$$

$$H = E + \frac{P}{\rho} \quad (4)$$

where e is the specific internal energy. In addition, x denotes the space coordinate, t the time, F the viscous friction force, q the heat flux, and g the gravitational acceleration. In the case of the HM, the assumption of mechanical equilibrium, i.e. no phase slip, is retained.

The system of partial differential equation (2) is an extension of the work previously done in (Oldenburg, 2007), (Celia & Nordbotten, 2009), by accounting for both a variable cross-sectional area and additional source terms. By analysing in more detail the various source terms appearing on the right-hand side of Eq. (2).
The frictional loss F in equation (2) can be expressed as

$$F = -f_w \frac{\rho u^2}{D_p} \quad (5)$$

where f_w is the Fanning friction factor, calculated using Chen's correlation (Chen, 1979), and D_p is the internal diameter of the pipe.

The gravitational term includes

$$\beta = \rho g \sin\theta \quad (6)$$

which accounts for the possible well deviation.

In Eq. (2) the source term Q accounts for the heat exchange between the fluid and the well wall. The corresponding heat transfer coefficient η is calculated using the well-known Dittus-Boelter correlation (Dittus & Boelter, 1930):

$$\eta = 0.023\, Re^{0.8} Pr^{0.4} \frac{k}{D_p} \tag{7}$$

where k, Re and Pr are the thermal conductivity, Reynold's number and Prandtl's number for the fluid. The heat exchanged between the fluid and the wall is calculated using the following formula:

$$q = \frac{4}{D_p}\eta(T_w - T) \tag{8}$$

T_w and T are the temperatures of the fluid and of the wall, respectively. Note that $T_w = T_w(x, t)$, i.e. T_w is not assumed constant, but variable with time and space.

Numerical method and injection well CO_2 inlet conditions

In this study, an effective model based on the Finite Volume Method (FVM), incorporating a conservative Godunov type finite-difference scheme (Godunov 1959, Radvogin et al. 2011, Cumber et al. 1994) is used. The FVM is well-established and thoroughly validated CFD technique. In essence, the methodology involves the integration of the fluid flow equations over the entire control volumes of the solution domain and then accurate calculation of the fluxes through the boundaries of the computed cells.

For the purpose of numerical solution of the governing equations they are written in a vector form (Toro 2010):

$$\frac{\partial \bar{Q}}{\partial t} + \frac{\partial \bar{F}}{\partial x} = S, \tag{17}$$

where

$$\bar{Q} = (\rho,\ \rho u,\ \rho e)^T,$$
$$F = \left(\rho u,\quad (\rho u^2 + P),\qquad u\left(\rho u e + \rho u^2 + P\right)\right)^T$$
$$S = (S^m,\ S^{mom},\ S^e)^T \tag{18}$$

$\bar{Q}$, F and S are the vectors of conserved variables, fluxes and source terms respectively. The source terms S^m, S^{mom} and S^e describe the effects of mass, momentum and heat exchange between the fluid and its surrounding respectively, as well as friction and heat exchange at the pipe wall.

4.1 Injection well and CO_2 inlet conditions

The data used in this study obtained from the Peterhead CCS project include the well depth and pressure and temperature profiles, along with the surrounding formation characteristics as presented in (Li et al., 2015; Shell UK, 2015) and reproduced in Table 1. The Peterhead CCS project is aimed to capture one million tonnes of CO_2 per annum for 15 years from an existing combined cycle gas turbine located at Peterhead Power Station in Aberdeenshire, Scotland. In the project, the CO_2 captured from the Peterhead Power Station would have been transported by pipeline and then injected into the depleted Goldeneye reservoirs. Despite the cancellation of the project funding, useful information was already available, given that the Goldeneye reservoir had been used for extraction of natural gas for many years.

Table 1: Goldeneye injection well and CO_2 inlet conditions (Shell UK, 2015)

Input parameter	Value
Wellhead pressure, bar	36.5
Wellhead temperature, K	280
Bottom-hole temperature, K	353.15
Well depth, m	2580
CO_2 injection mass flow rate, kg/s	linearly ramped-up to 38.5 kg/s in 5 minutes
Injection tube diameter, m	0.125m
CO_2 inlet pressure, bar	115
CO_2 inlet temperature, K	277.15
Outflow	$A = 0$ $B = 1.3478 \times 10^{12}$ Pa^2s/kg $C = 2.1592 \times 10^{10}$ Pa^2s^2/kg^2 $P_{res} = 177$ bar

Figure 3 shows the initial distribution of the pressure and the temperature along the well. Based on this initial pressure and temperature distribution obtained from the Goldeneye CO_2 injection well, the CO_2 is in the gas phase in the first 400 m along the well and dense phase within the rest of the well depth. This initial condition is the same for all 3 ramp-up injection cases considered. In addition, a CFL condition of 0.3, $\Delta t = 10^{-4}$s and 300 computational cells were employed. In particular, this study considers linearly ramped-up injection mass flow rates from 0 to 38.5 kg/s in 5 minutes, 30 minutes and 2 hours. The varying ranges of CO_2 injection mass flow rates ramped-up with time from 0 to 38.5 kg/s at CO_2 feed pressure of 115 bar employed in this study is essential to understanding the optimum injection ramp-up duration.

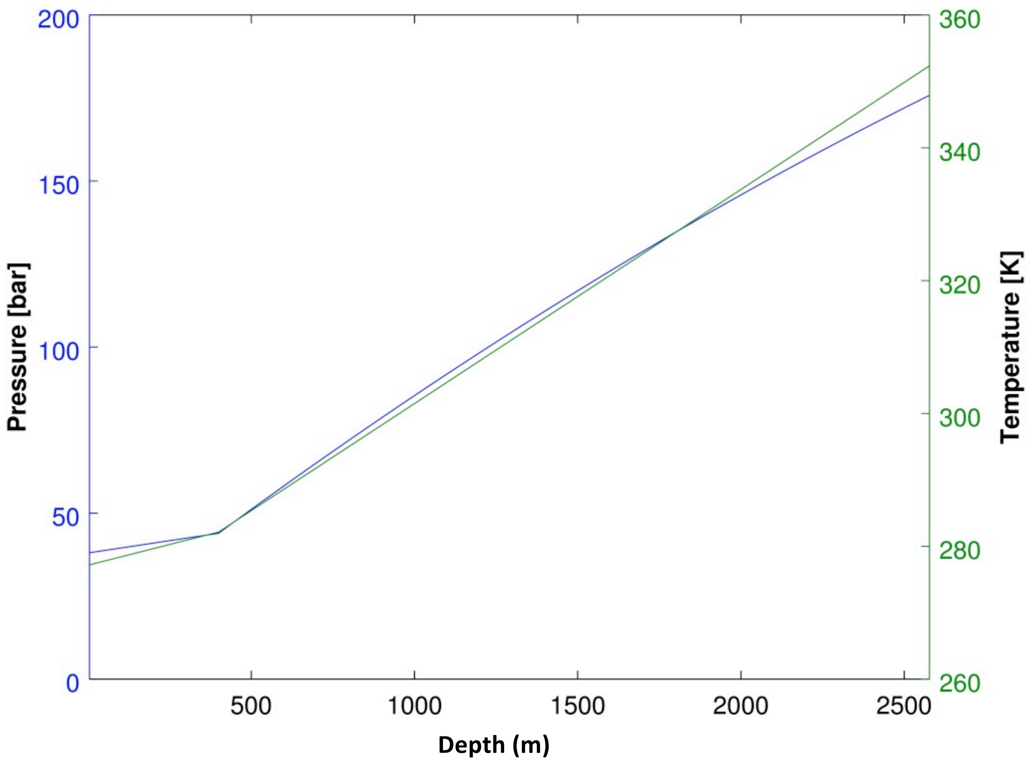

Figure 4: Initial distribution of the pressure and the temperature along the well

The presence of CO_2 stream impurities is a well-established study and depending on the capture technology various amounts of impurities such as hydrocarbons, nitrogen, oxygen, hydrogen, carbon monoxide, hydrogen sulphide, argon and etc. can be present in the captured CO_2 stream (Wetenhall, Aghajani, et al., 2014). Table 2 shows the various CO_2 stream compositions according to post-combustion, pre-combustion and oxy-fuel capture technologies presented by Porter et al, (2015) is employed in this study CO_2 impurities simulations.

Table 2: CO_2 stream % compositions based on the various capture technologies (Porter et al., 2015)

Component	**Post-combustion**	**Pre-combustion**	**Oxy-fuel**
CO_2 %v/v	(99.75)	(97.95)	(85)
Ar %v/v	(0.02)	(0.03)	(4.47)
N_2 %v/v	(0.09)	(0.9)	(5.80)
O_2 %v/v	(0.03)	-	(4.70)
CO ppmv	-	(400)	(50)
H_2S ppmv	-	(100)	-
H_2 ppmv	-	(20)	-
SO_2 ppmv	(20)	-	(50)
H_2O ppmv	(600)	(600)	(100)
NOx ppmv	(20)	-	(100)
CH_4 ppmv	-	(100)	-

These impurities are mainly identified to have significant impact on the behaviour of CO_2 during pipeline transportation and very significant changes in the thermodynamic properties of CO_2 stream were previously predicted (see Brown et al, 2013; Martynov et al , 2013).

- Effects of impurities on phase behaviour of CO_2 streams

Fig 4 shows the CO_2 streams phase envelopes calculated using the Peng-Robinson equation of state for the following cases (Wang et al., 2011): the CO_2 stream from oxyfuel combustion in a fluidized bed pilot plant combustor in Canmet Energy, containing 5.2 vol % O_2, 221 ppm CO, 1431 ppm SO_2 and 243 ppm NO; while the CO_2 stream from a zero-emissions process proposed by Canmet Energy, containing 1.05% CO, 1.7% SO_2, 0.32% H_2 and 690 ppm H_2S;

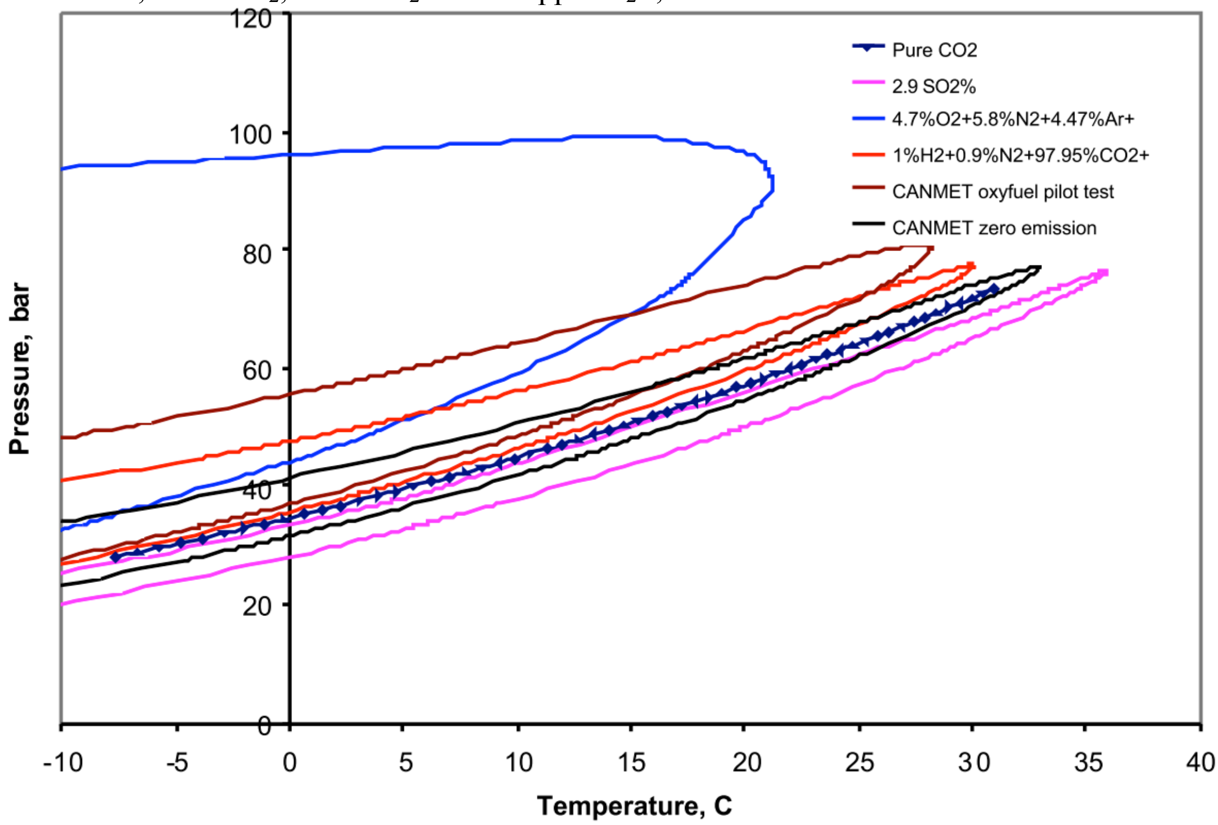

Figure 4: Calculated phase envelopes for pure CO_2 and CO_2 mixtures (Wang et al., 2011)

From Fig. 4 it can be seen that the critical temperature and pressure of the mixtures are quite different from that of the pure CO_2. N_2, O_2, Ar and H_2 show the greatest effect of increasing the saturation pressure of the liquid and decreasing the critical temperature. One extreme case is the mixture from oxyfuel combustion containing 5.8% N_2, 4.7% O_2, 4.47% Ar and other impurities at ppm level. The critical temperature decreases by about 10°C in comparison with that of pure CO_2, and the liquefaction pressure increases by over 50 bar. On the other hand, SO_2 results in a decrease in the saturation pressure and an increase of the critical temperature, as is expected from the high critical temperature of pure SO_2 (157.6°C). It can also be seen that low-concentration impurities, such as CO and NOx would not significantly affect the phase. Therefore, before the steady injection of CO_2 into the reservoir can be started, it is necessary to perform time-dependent operations to estimate important wellbore pressure and temperature behaviours of the injected CO_2. Such operations include start-up, shut-in and emergency shut-down, which prove to be critical in the overall design of the well (Böser & Belfroid, 2013). Even after steady injection conditions are reached the well may be shut in and started up for maintenance of the upstream transportation system or other routine checks. It is therefore of paramount importance to be able to predict the behaviour of the CO_2, in terms of pressure and temperature along the full length of the well, to characterise and quantify potential risks (Li, *et al*, 2015).

Results and discussion

The results obtained following the simulation of the transient flow model for the injection of CO_2 with various stream impurities into highly depleted oil/gas fields are presented and discussed in details. Beginning at the top inlet of the injection well down to the bottom outlet into the reservoir, the pressure and temperature profiles are presented. Specifically, the pressure and temperature variations at the top of the well and the corresponding effects along the wellbore can be seen in the profiles.
Fig. 5 shows the variation in pressure with time at the top of the well for 5 mins ramp-up injection time. The start-up injection data shows a rapid drop in pressure of the incoming CO_2 at 115 bar to as low as 74.8 bar. Following the initial pressure drop is a recovery over the ramp-up duration until a steady state is attained.

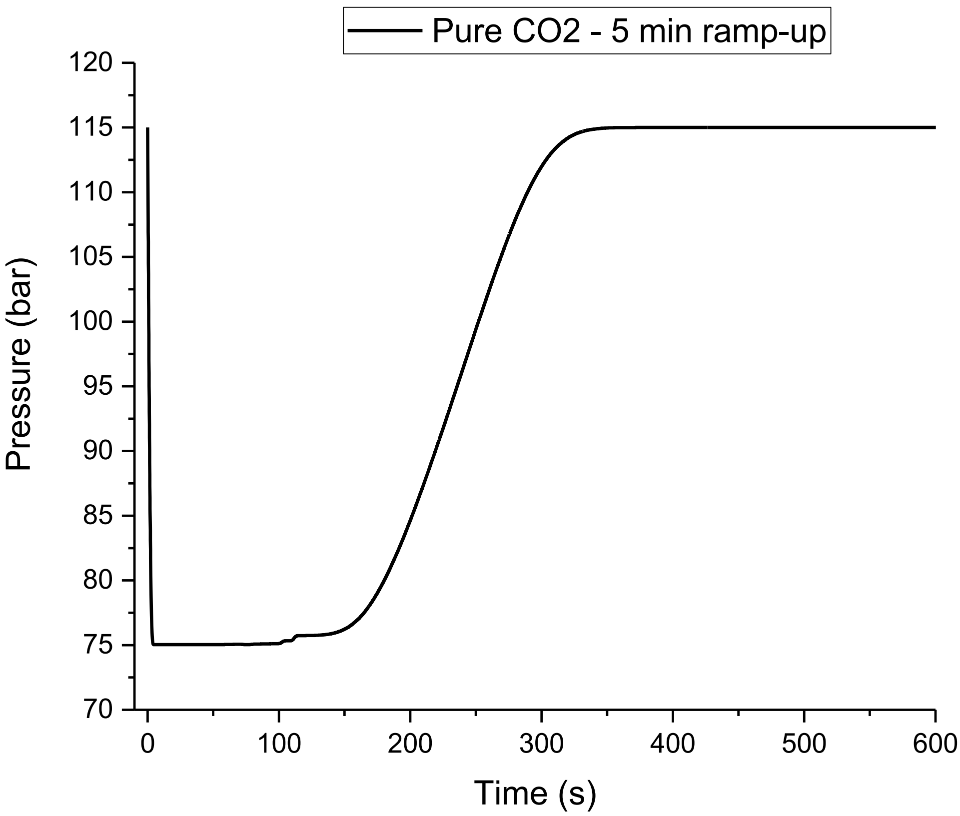

Figure 5: CO_2 wellhead pressure variation with time for 5 mins ramp-up injection
Fig. 6 shows the variations in pressure with time at the top of the well for pure CO_2 and it mixtures. As can be seen, the pressure profiles of the mixtures are quite

different from that of the pure CO_2. Oxyfuel and pre-combustion captured CO_2 mixtures show the greatest effect of pressure drop at the start of injection. The mixture from oxyfuel combustion containing 5.8% N_2, 4.7% O_2, 4.47% Ar and other impurities at ppm level recorded the highest pressure drop of 69 bar from the inlet pressure of 115 bar. On the other hand, pre-combustion captured CO_2 stream containing 0.09 % N_2, 0.03 % O_2, 0.02 % Ar and other impurities at ppm level showed a minimal drop in pressure. The results obtained in this study clearly show the impacts of stream impurities on the captured CO_2 at the injection well. Hence, minimising the level of impurities before injection is highly important to avoid higher pressure drop during the process.

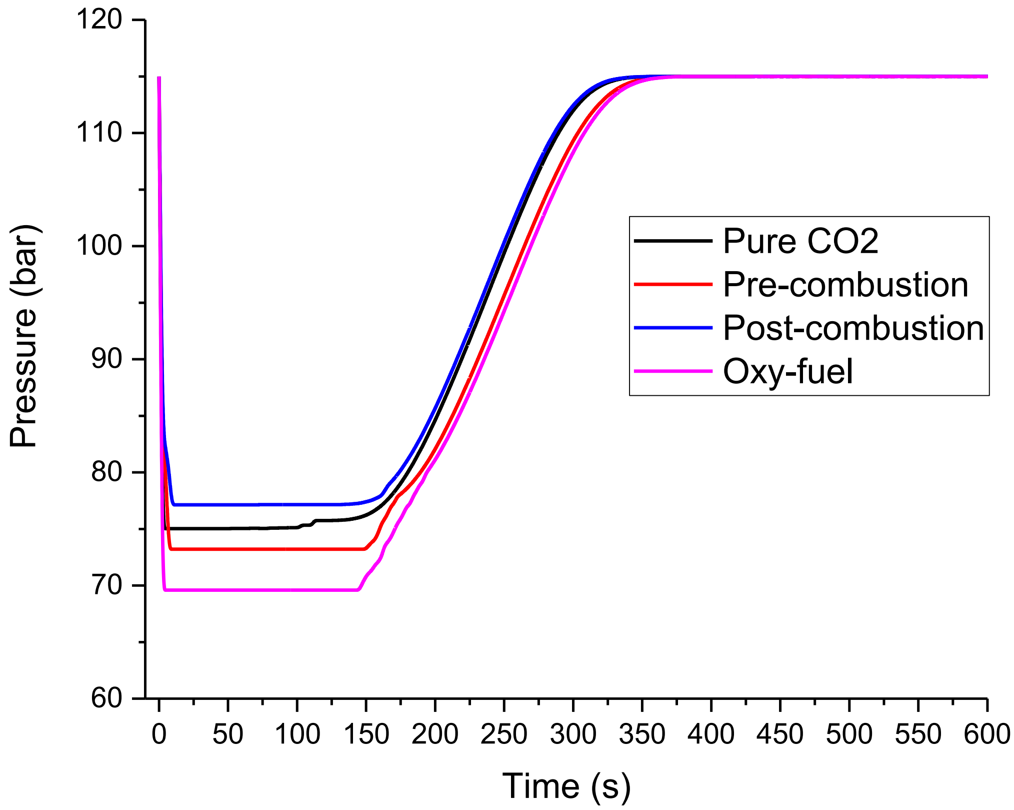

Figure 6: Variations in pressure with time at the top of the well for pure CO_2 and it mixtures

Fig. 7 shows the variation in temperature with time at the top of the well for 5 mins ramp-up injection time. The start-up injection data shows a rapid drop in temperature following a corresponding pressure drop of the incoming CO_2 at 115 bar to as low as 74.8 bar. The temperature dropped rapidly from 277 K to 251 K within the first 120 sec. Following the massive temperature drop is a recovery over the ramp-up duration until a steady state is attained.

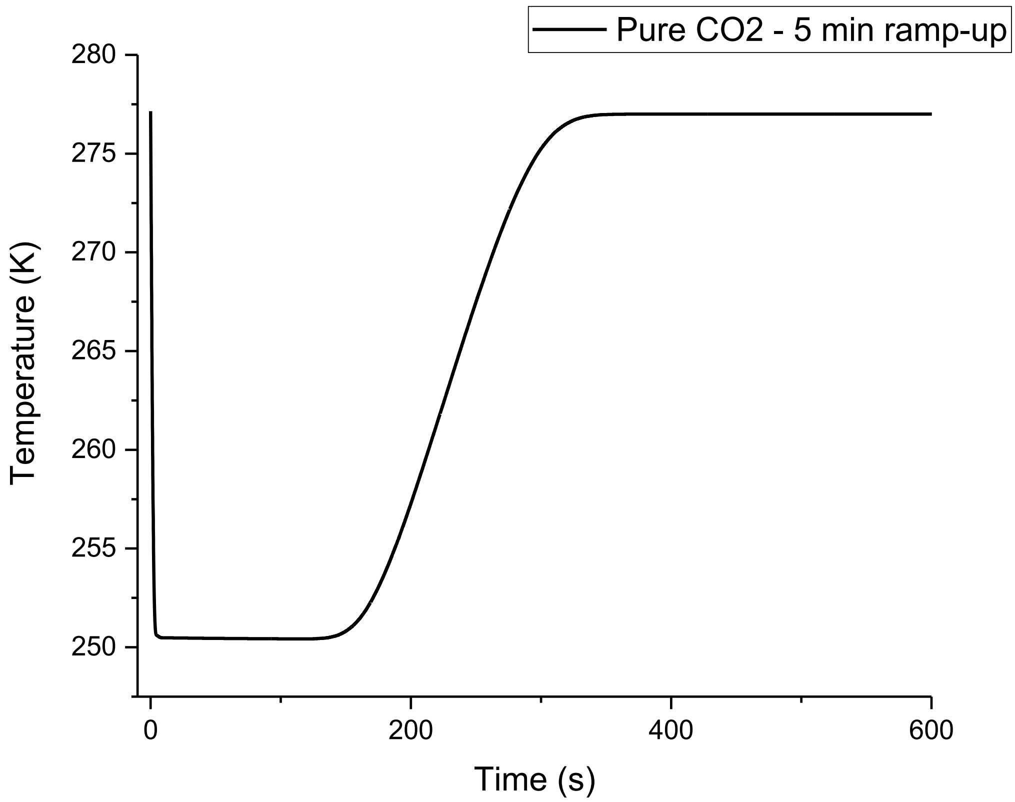

Figure 7: Variation in temperature with time at the top of the well for 5 mins ramp-up injection time

Fig. 8 shows the variations in temperature with time at the top of the well for pure CO_2 and it mixtures. As can be seen, the temperature profiles of the mixtures are quite different from that of the pure CO_2. Oxyfuel and pre-combustion captured CO_2 mixtures show the greatest impact on temperature drop at the start of injection. The mixture from oxyfuel combustion containing 5.8% N_2, 4.7% O_2, 4.47% Ar and other impurities at ppm level recorded the highest temperature drop of 226 K from the inlet temperature of 277 K. On the other hand, pre-combustion captured CO_2 stream containing 0.09 % N_2, 0.03 % O_2, 0.02 % Ar and other impurities at ppm level showed a minimal drop in temperature. The results obtained in this study clearly show the impacts of stream impurities on the captured CO_2 at the injection well. Hence, minimising the level of impurities before injection is highly important to avoid higher temperature drop during the process that may lead to ice formation with interstitial water molecules present in the mixture. Such low temperatures may also cause thermal shock on the steel leading to its crack and ultimate escape of injected CO_2.

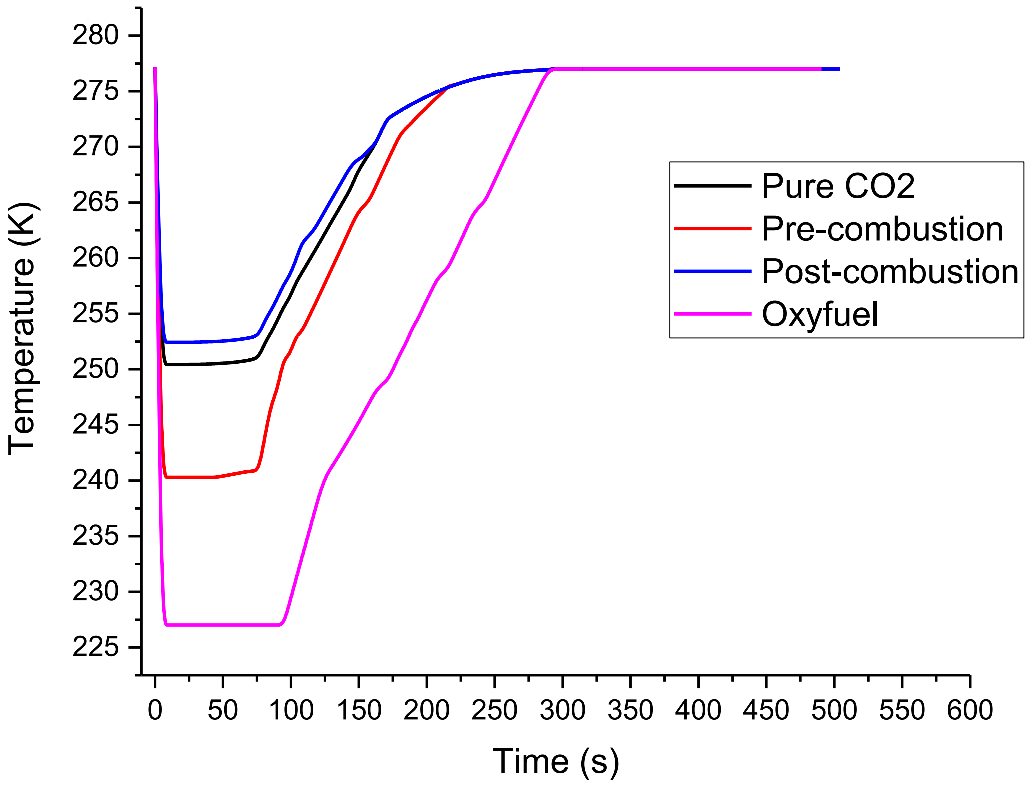

Figure 8: Variations in temperature with time at the top of the well for pure CO_2 and it mixtures

Figs. 9 and 10 respectively show the pure CO_2 corresponding results for the temperature and pressure profiles along the length of the well during the 5 mins ramping up process at different selected time intervals of 10, 100, 200 and 300 seconds. The pressure profiles show continues pressure build up along the wellbore during the 5 mins injection ramp up. On the contrary, the temperature profiles show a significant temperature drop for the 10, 100 and 200 s well profiles in comparison with the initial well temperature profile at 0 s. The well temperature profile at 300 s shows significant recovery approaching the initial well temperature profile. As can been seen in Fig. 10 the temperature profile along the injection wellbore shows an improve profile as the ramp up injection duration reaches 300 s compared with the 10, 100 and 200 s cases. In other words, operating a fast injection ramp-up is recommended to rapidly increase the injection flow rate with time and consequently minimise the drop in temperature along the wellbore.

This means that the presence of impurities in the CO_2 stream may further affect the temperature along the wellbore. For instance, the oxyfuel captured CO_2 stream with higher levels of impurities may impose temperatures below 0 ^oC on the wellbore down to the bottom of the well. The effect of such low temperatures on the injection system is highly significant and accounted as a critical factor for safe injection of CO_2. Based on the fact that there is a possibility of interstitial water molecules present within the wellbore during injection, the formation of ice is likely and may pose significant safety risks.

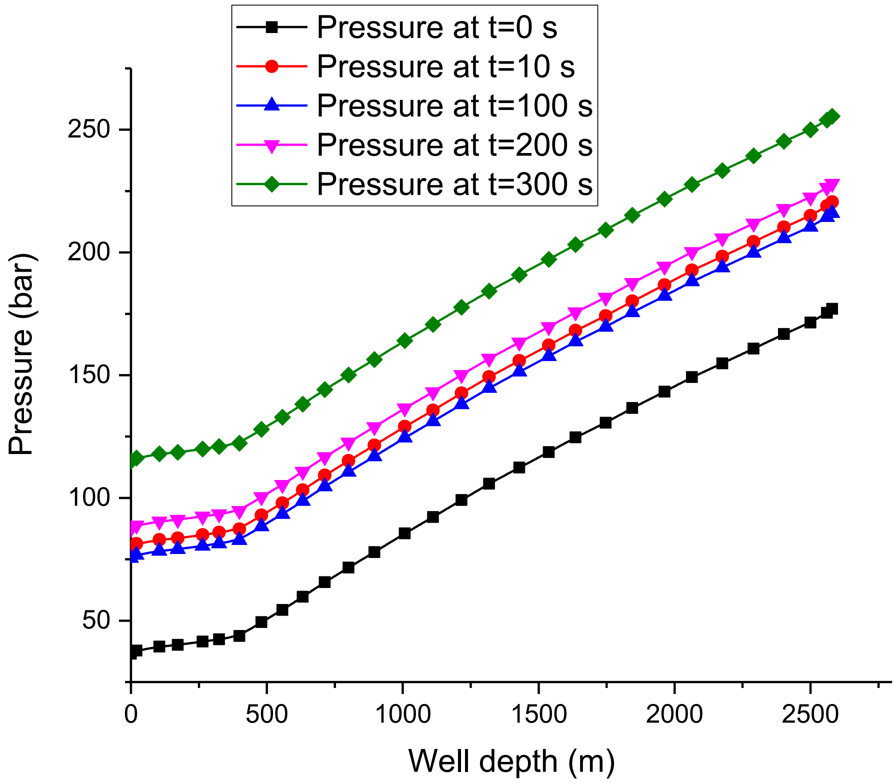

Figure 9: Pure CO_2 wellbore pressure profiles at selected time intervals

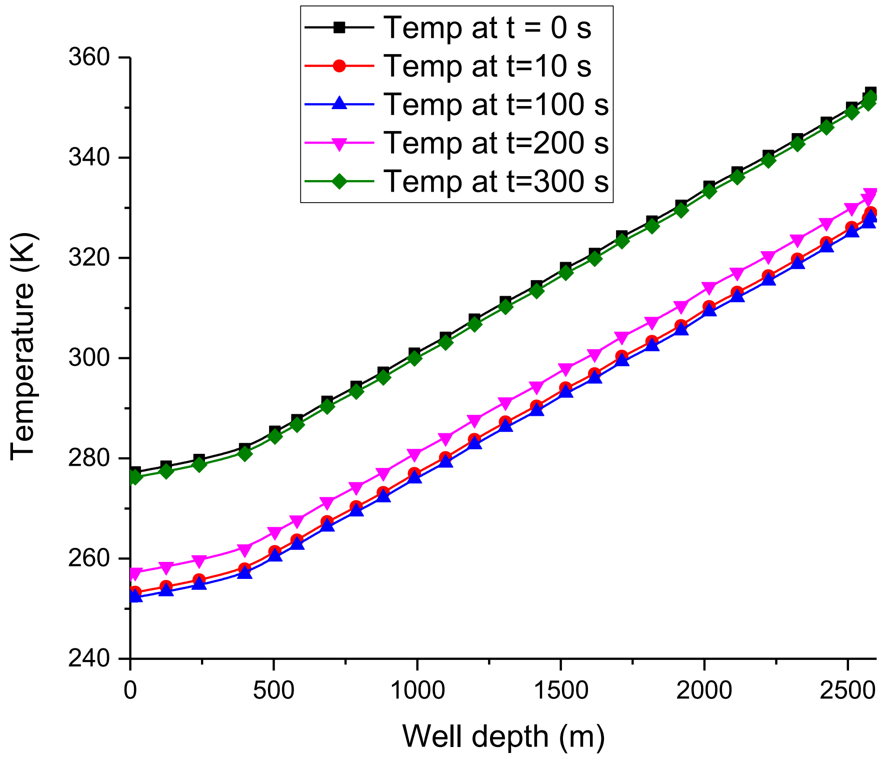

Figure 10: Pure CO_2 wellbore temperature profiles at selected time intervals

Conclusion and future work

This study has led to the development and testing of a rigorous HEM for the simulation of the highly-transient multi-phase flow phenomena taking place in wellbores during the start-up injection of high pressure CO_2 streams into depleted gas fields. In practice, the model developed can serve as a valuable tool for the development of optimal injection strategies and best-practice guidelines for the minimisation of the risks associated with the start-up injection of CO_2 streams with various impurities into highly-depleted gas fields. Specifically, we have shown the impacts of CO_2 stream impurities on wellbore pressure and temperature profiles to enhance safe injection. However, previously existing knowledge could not provide solutions to the stream impurities problems that will be inevitably encountered. The results obtained from the present work are expected to have significant applications or implications to all CO_2 storage operations.

It is critically important to bear in mind that the above results are not universal. On the contrary, they are only based on the case study investigated on a highly depleted gas field. Each injection scenario must be individually examined in order to determine the likely risks. However, in this study we have developed the computational tool needed to make such assessment.

The experience gained during this work has opened to us new interesting areas of research, which would be worth investigating. We highlight here two main potential developments. Firstly, an appropriate two-fluid model with flow-regime-dependent correlations will have to be developed and analysed to the full impacts of the stream impurities. Secondly, it would be worth considering a coupling between the HEM in the well and an appropriate Darcy solver for all the reservoir variables. In so doing, we would be able to take into account more directly those properties of the reservoir (pressure, porosity, permeability, etc.) which vary in time as well and depend on the actual exploitation history of the reservoir under investigation.

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Optimal Design and Analysis of Single-Stage Flyback PV Micro-inverter

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Abstract
Over the last decades, solar energy systems have aroused much interest due to increased concern for the environment. Photovoltaic (PV) module based electric power generation systems present promising solutions to ensure sustainable, abundant, inexhaustible, and environmentally friendly energy. In view of the foregoing, converters used in PV systems is emerging as a major component. Micro-inverters (MIs) known as module based type of inverters, which are attached to individual PV modules as an operative interface between PV and utility grid, provide an efficient, reliable, and cost effective power generation possibility. The salient features of MIs can be expressed as lower installation cost, improved energy harvesting by allowing individual maximum power point tracking (MPPT), plug-N-play operation, and improved system efficiency. This paper presents a detailed analysis of modelling and control of single-phase grid connected single-stage flyback PV MI. A 205W single-stage flyback MI is investigated with respect to power circuit design and component selection criteria, operation modes, MPPT control, injected grid current control, and grid synchronisation. To assess and validate feasibility of analysed 205W single-stage flyback MI, a simulation model is constructed by using an electromagnetic transient software package PSCAD/EMTDC.

Keywords: Very-short term, Energy forecasting, Household, Smart grid integration, Artificial intelligence, Decision trees, Genetic algorithm, Artificial neural networks, Support vector machines, Mean absolute error

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Introduction

The energy source demand for the electricity generation grows over the world for the past decades and will continue to grow in the forthcoming decades. The shortcomings of the sources used for electricity generation include coal, natural gas, petroleum, and other liquid fuels aroused much interest for renewable energy sources. Also, utilisation of these sources reveals a huge environmental problem named as global warming, which is one of the most significant threats for future of global climate change. In this manner, the renewable energy sources play an important role for the future of humanity due to being sustainable, abundant, inexhaustible, and environmentally friendly (Çelik et. al, 2018). An evaluation of the current state-of-cumulative installed renewable energy capacity for different renewable energy technologies are given in Figure 1.

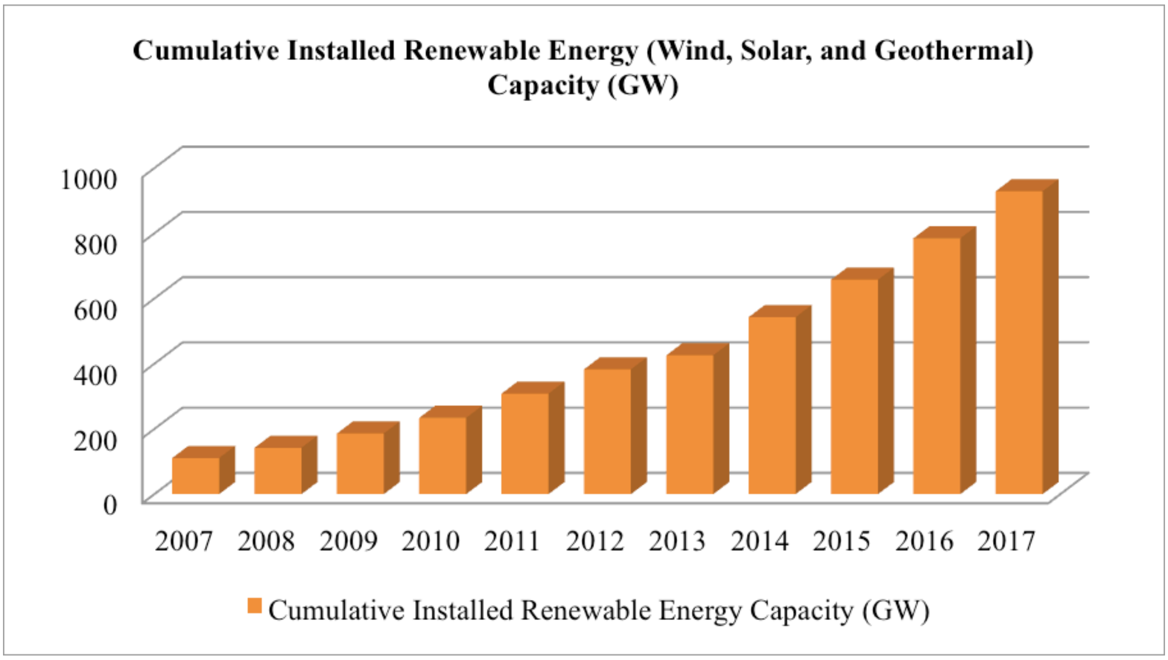


Figure 1. The cumulative installed renewable energy capacity (BP, 2018)

Among the renewable energy sources, solar energy gains acceptance in terms of being applicable in almost every place that is convenient for placement of PV panels and demonstrates exponential growth with the support programs of governments. When the cumulative installed capacity of mostly utilised renewable energy sources is investigated, solar energy can be considered as one of the most promising source of energy and constitutes 43% of total installed renewable energy capacity as shown in Figure 2 (Hasan et. al, 2017).

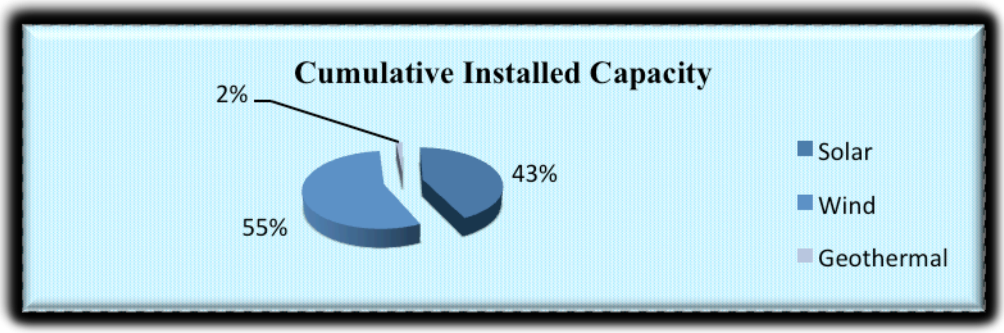


Figure 2. Percentage of solar energy among the renewable energy sources (BP, 2018)

The total installed capacity of PV systems exceeds 400 GW at the end of 2017. The tremendous potential of PV systems can be clearly seen from the Figure 3. Especially in 2017, deployment of solar power had a very strong year by showing an increase of about 100 GW.

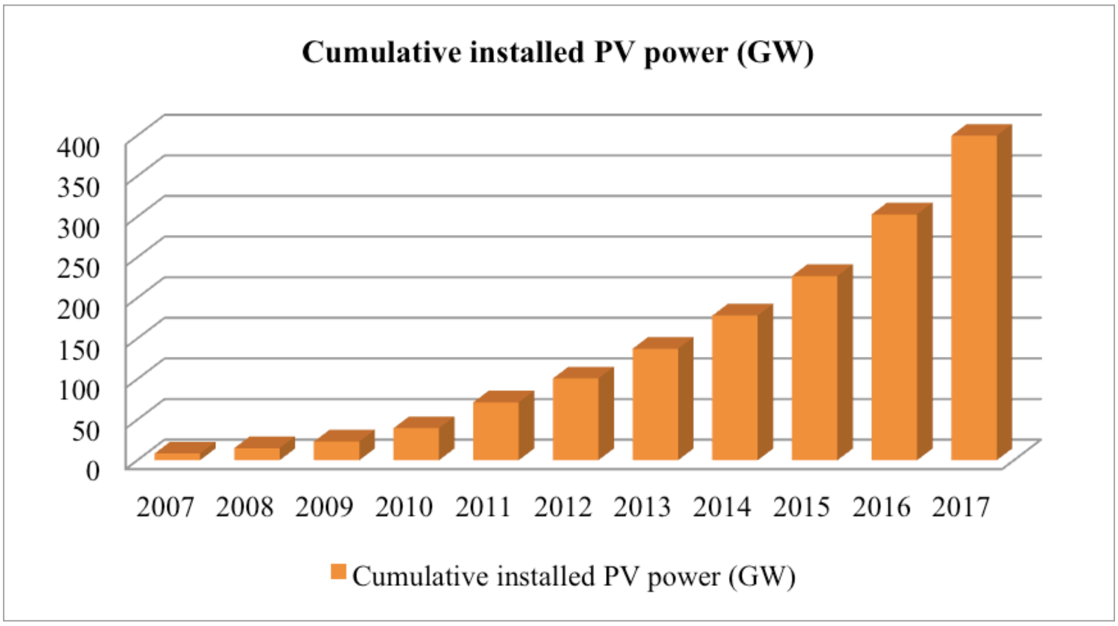


Figure 3. Cumulative installed PV power (BP, 2018)

Besides having so many merits such as easy to install, no noise, almost maintenance free, inexhaustible, and environmentally friendly, PV systems suffer from the initial cost of purchasing and installing PV panels (Çelik et. al, 2015). The rapid cost decline and efficiency increment for PV technologies is critical. In addition to studies carried on increasing PV cell efficiency, researching on power electronics based devices for efficient energy harvesting is an effective and economical way to enhance the overall PV system efficiency (Salam et al., 2013; Sher and Addoweesh, 2012; Çelik and Teke, 2017). Inverters can be considered as one of the key components of the PV systems. The configurations of the PV panels and appropriate inverter selection have a direct effect on cost and efficiency of the entire system. Depending upon the solar panel placement, the PV system can be configured in four different types. There are centralised inverters, string inverters, multi-string inverters, and module based inverter also known as MI configurations available as demonstrated in Figure 4.

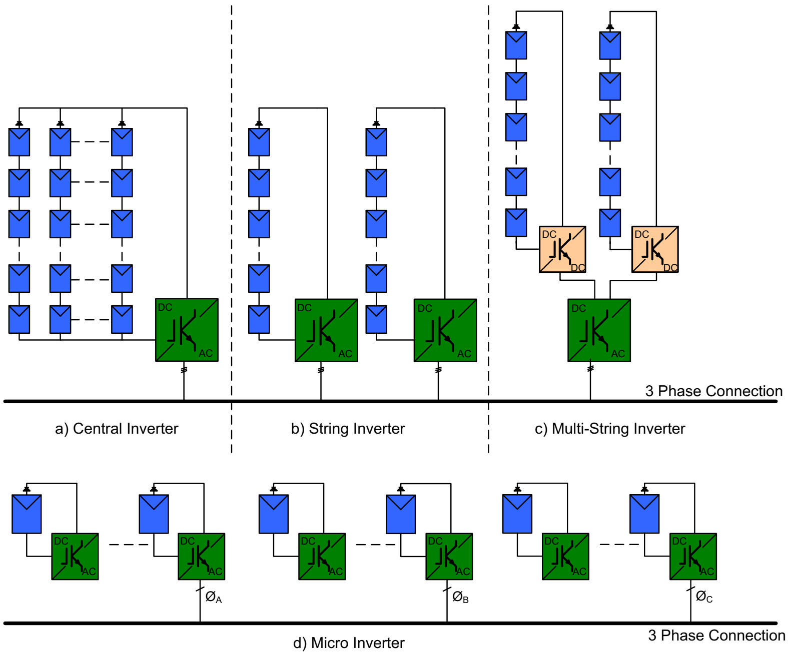


Figure 4. Different inverter design configurations

The MIs are becoming more and more popular for small-scale power applications with the benefits of having better overall efficiency, possibility to become plug-N-play device, lack of DC connections, alleviation of arc and firing risk, eliminating the mismatch losses between the PV panel and the inverter, and having individual MPPT controller (Kyritsis et al., 2008; Zhang et al., 2013). Having individual MPPT controller will attain maximum power from PV modules independent of the atmospheric conditions and partially shading conditions (Çelik and Teke, 2017). The MIs are mostly designed for a power rating between 50 and 400 W with power conversion efficiencies above 90% (Çelik et al., 2018; Hasan and Mekhilef, 2017; Trujillo et al., 2016). Many converter topologies that contain either a single or multi-stage power conditioning system have been developed for the MIs (Lai et al., 2016). In single stage configuration, it is aimed to achieve MPPT control, voltage regulation and DC to AC conversion in a single-stage. Recently, the single-stage flyback MIs shown in Figure 5 emerges as an attractive choice for PV applications.

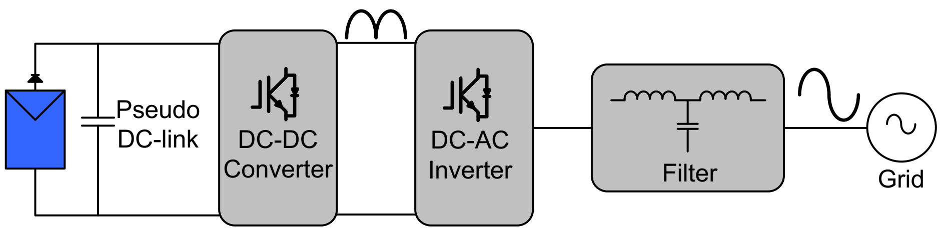


Figure 5. Block diagram of the single-stage MI

The promising aspects of the single-stage flyback MI can be expressed as requiring fewer electronic equipment, high efficiency, having galvanic isolation, high reliability, low volume, and robust control structure with simple design (Edwin et al., 2014; Gao et al., 2014; Kyritsis et al., 2008; Nanakos et al., 2015). In single-stage topology, the decoupling capacitor is placed at the input side and it is expected to perform both MPPT and rectified sine current shaping operations in one stage.

Rectified sinusoidal waveform is delivered to the network by H-bridge unfolder stage and output filter. This configuration is also known as MIs with pseudo DC-link.

In this paper, the flyback inverter operating in discontinuous conduction mode (DCM) is investigated with analytical equations. A detailed analysis of modelling and control of the single-phase grid connected single-stage flyback PV MI is presented. A 205W single-stage flyback MI is investigated with respect to power circuit design and component selection criteria, operation modes, MPPT control, injected grid current control, and grid synchronisation. To assess and validate feasibility of analysed 205W single-stage flyback MI, a simulation model is constructed by using an electromagnetic transient software package PSCAD/EMTDC.

Circuit Topology of Current Source Flyback Inverter and Operation

The circuit topology of the studied DCM operated current source single-stage flyback MI is shown in Figure 6. Due to performing both MPPT and rectified sine current shaping operations in DC-DC converter part, the model is expressed as single-stage.

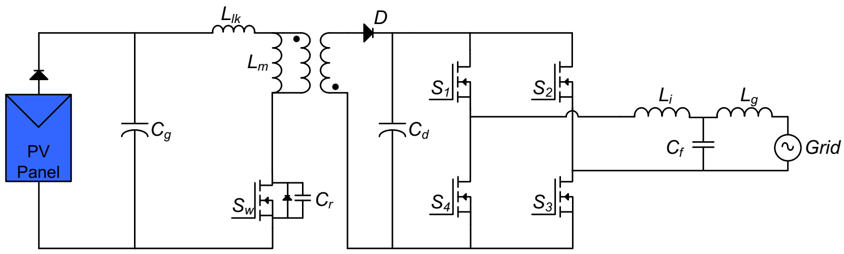


Figure 6. Circuit topology of current source single-stage flyback MI

DCM operation is widely used in flyback MI module applications. This operation mode has three time interval and peak current value of each switching cycle is proportional to the sinusoidal envelope. In the first time interval, transformer is charged during the on time and then in the second time interval, the transformer is discharged during the off time. In the third time interval between the off time and beginning of the switching cycle, there is no current flow through the transformer (Kyritsis et al., 2008). Ensuring zero current turn on of main switch of flyback converter and turn off of output diode reduces the switching loss and eliminating the reverse recovery problem. Also, DCM operation eliminates right half plane (RHP) zero causing difficulties to stabilize the control loop for wide input voltage range. However, the peak value of the magnetising current is high when compared to continuous conduction mode (CCM) and boundary conduction mode (BCM). The high magnetising current rating increases the winding losses of transformer, conduction loss, and switching loss. This operation contains fixed frequency and variable duty cycle that changes according to the reference signal taken from the MPPT controller (Lai, 2014). The block diagram of the control circuit for the DCM operation is given in Figure 7.

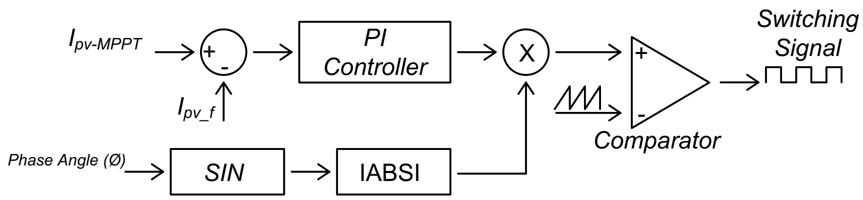


Figure 7. Block diagram of the control circuit for the DCM operation (Kyritsis et al., 2008)

In order to provide the converter to operate in DCM, the condition given in the Eq. 1 should be ensured as

$$t_{off-pk} \leq T_s - t_{on-pk} \tag{1}$$

where "t_{off-pk}" is the switch off time, "t_{on-pk}" is the switch on time, and "T_s" is the switch cycle time.

The current passing through the transformer drop to zero when the main switch is off. When the main switch is off, the voltage reflected to the primary of the transformer will be

$$V_{grid} = V_{grid-pk} \sin(wt) \tag{2}$$

where "V_{grid}" is the grid voltage and "$V_{grid-pk}$" is the peak grid voltage.

For the DCM operation, it is important to ensure enough time for the magnetising current becomes to zero from its peak value. During the off time

$$t_{off-pk} = L_m \frac{I_{in-pk}(t)}{N V_{grid-pk}} \tag{3}$$

where "L_m" is the magnetising current, "$I_{in-pk}(t)$" is peak value of the input current, and "N" is the turns ratio of the transformer.

During the on time

$$V_{in} = L_m \frac{i_{in}(t)}{dt} \tag{4}$$

$$t_{on-pk} = L_m \frac{I_{in-pk}}{V_{in}} \tag{5}$$

$$t_{on-pk} = d_{pk} \frac{1}{fs} \tag{6}$$

$$t_{off-pk} = \frac{V_{in} d_{pk}}{N V_{grid-pk} fs} \tag{7}$$

where "V_{in}" is the input voltage, "d_{pk}" is the peak duty cycle, and "fs" is the switching current.

From the Eq. 7, it can be seen that in order to provide the converter operate in DCM mode the value of the d_{pk} and N should be adjusted. By using the Eq. 1 and the Eq. 7 can be rearranged as shown below

$$T_s - t_{on-pk} \geq \frac{V_{in} d_{pk}}{N V_{grid-pk} f s} \quad (8)$$

By arranging the Eq. 8 d_{pk} and N can be calculated as shown below

$$d_{pk} \leq \frac{1}{\frac{V_{in}}{N V_{grid-pk}} + 1} \quad (9)$$

$$N \geq \frac{V_{in}}{V_{grid-pk}} \left(\frac{1}{d_{pk}} - 1\right)^{-1} \quad (10)$$

The value of the magnetising inductance is another important parameter in terms of storing sufficient energy to be fed to the grid. The transformer magnetising inductance can be calculated by using the following equation;

$$L_m = \frac{1}{2} \frac{\alpha^2 d_{pk}^2}{P_{rated} f s} V_{grid-rms}^2 \quad (11)$$

$$\alpha = \frac{V_{in-min}}{V_{grid-pk}} \quad (12)$$

where "P_{rated}" is the rated power, "$V_{grid-rms}$" is rms value of the grid voltage.

Decoupling capacitor sizing is also important in terms of achieving an efficient MPPT operation (Hu et al., 2013). Due to being an operative interface between the PV panel and grid, the defined decoupling capacitor should cope with the instantaneous power mismatches. The capacitance of decoupling capacitor can be calculated by using the following equation;

$$C_D = \frac{P_{rated}}{2\pi f_{grid} V_{in} \Delta V} \quad (13)$$

where "C_D" is capacitance of the decoupling capacitor, "f_{grid}" is the grid frequency, and "ΔV" is the ripple on the voltage and should be below 5%.

Design Procedure for Single-Stage Flyback MI

When we consider the aforementioned advantages of single-stage flyback MI operating in DCM mode seems as an attractive solution for PV MI applications. It should be noted that the design procedure contains parameters related to each other (Mukherjee, 2013; Kavurucu, 2014). It is aimed to ensure the smallest volume for the defined rating power of inverter.

- By taking into account the Eq. 9 and Eq. 10, peak duty cycle and turns ratio of the transformer can be determined. It is crucial to provide that the flyback inverter operates in DCM mode. In view of this, required peak duty cycle and turns ratio values can be derived for different input voltage values.

- When operation in DCM mode is considered, the total conduction time should be less than the switching time period. By using Eq. 7, variation of conduction time with respect to turns ratio can be derived.
- "α" is another important parameter that needs to be determined, which directly affects the magnetising inductance of the transformer.
- Afterwards, the magnetising inductance of the transformer is determined.

Simulation Results

The validity of the investigated model is verified by constructing a PSCAD/EMTDC model with the following specifications;

- Input voltage = 29 V
- Input Current = 7.08 A
- Input Power = 205 W
- Open circuit voltage = 36.17 V
- Short circuit current = 7.5 A

The power circuit parameters are also given in Table 1.

Table 1. Power circuit parameters of the simulated model

Parameter	Values
Decoupling Capacitor	15.4 mF
Magnetizing Inductance	12.15 uH
Turns Ratio (N2/N1)	5
Switching Frequency	40 kHz
Bus Capacitor	400 nF
Filter Inductance (*Li* - *Lg*)	720 uH – 360 uH
Filter Capacitor (*Cf*)	880 nF
Damping Resistor	5 ohm
Grid Parameters	0.001 ohm – 15 uH

The simulated power circuit of the single-stage flyback MI, which consists of flyback converter, H-bridge unfolder, and output filter, is shown in Figure 8.

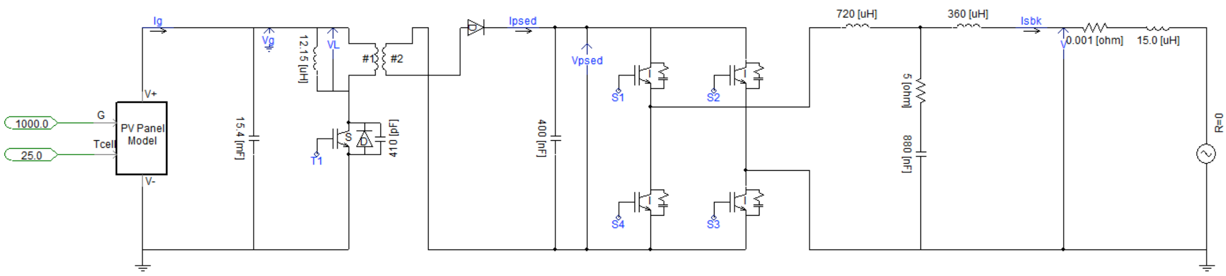


Figure 8. The simulated power circuit of the single-stage flyback MI

As it can be seen from Figure 9, PV output voltage oscillates around 29 V and with a current value of 7 A.

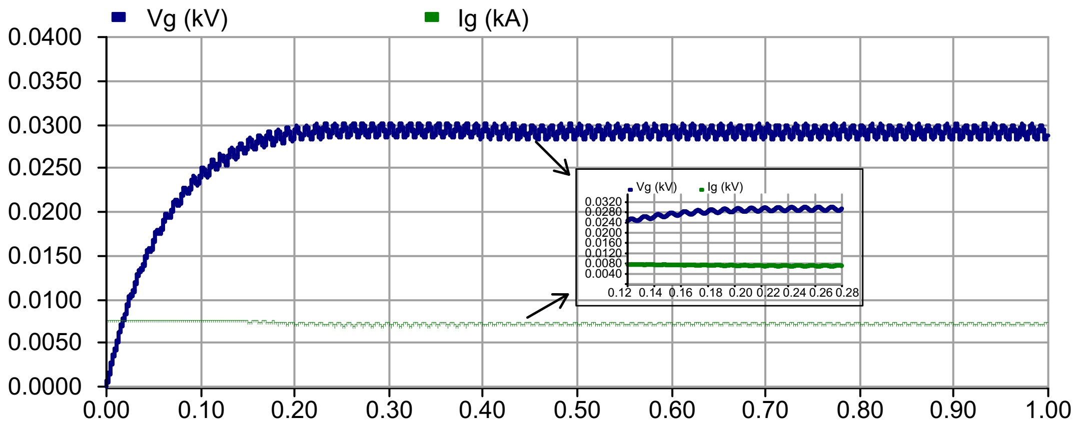


Figure 9. PV panel output voltage and current

In this study, perturb and observe (P&O) MPPT method is used for achieving the maximum power derivation from the PV panel. The output of the P&O MPPT block is used as a reference value in control block of single-stage flyback MI. In Figure 10, MPPT performance of the P&O method is shown. The reference value oscillates around 7.05 A.

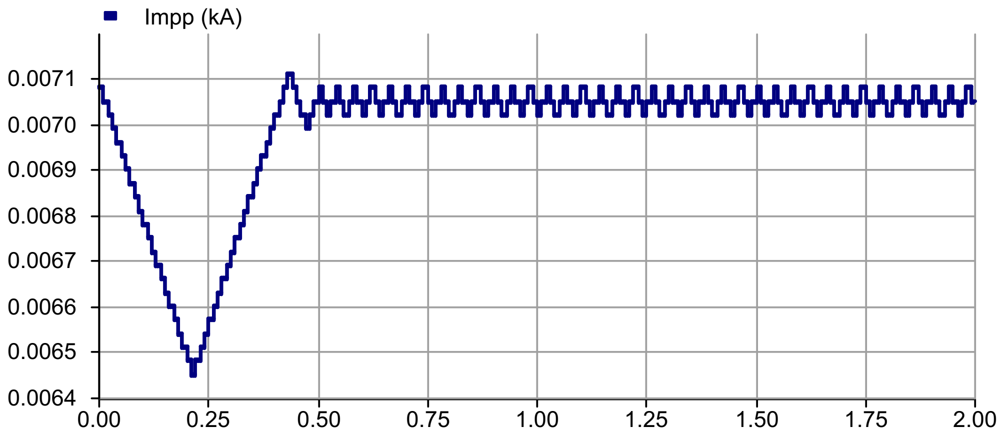
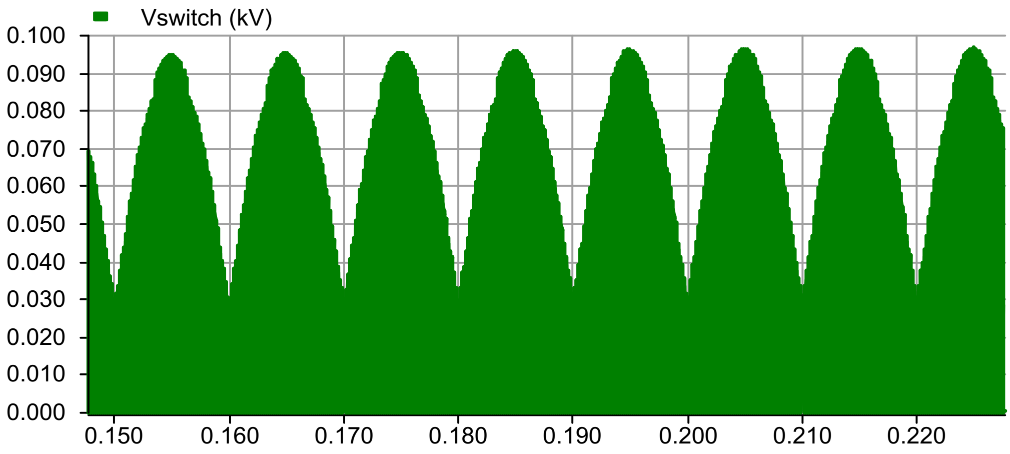
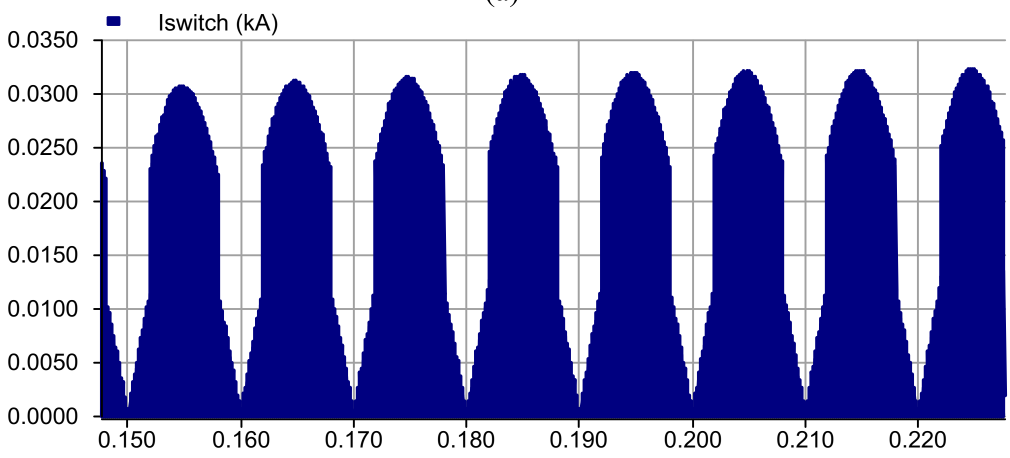


Figure 10. MPPT performance of the P&O method

In Figure 11, it can be seen from the switch current and switch voltage that the converter operates in DCM mode. The peak value of the current passing through the main switch reaches to 33 A and the peak value of the voltage across the main switch seems nearly 100 V.



(a)



(b)

Figure 11. (a) Voltage across the main switch (b) Current passing through the main switch

As it can be seen from Figure 12, rectified sinusoidal waveform on the pseudo DC-link capacitor fluctuates in duplicate of grid frequency. This rectified sinusoidal waveform is delivered to the network through the H-bridge unfolder stage and output LCL filter.

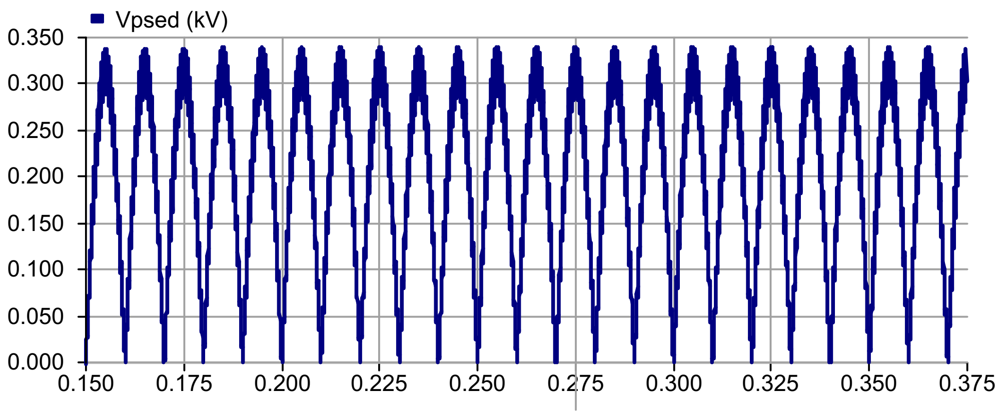


Figure 12. The rectified sinusoidal waveform across the bus capacitor

Figure 13 demonstrates the injected grid current for full load output of 180 W. Also the grid current harmonic is below 3%.

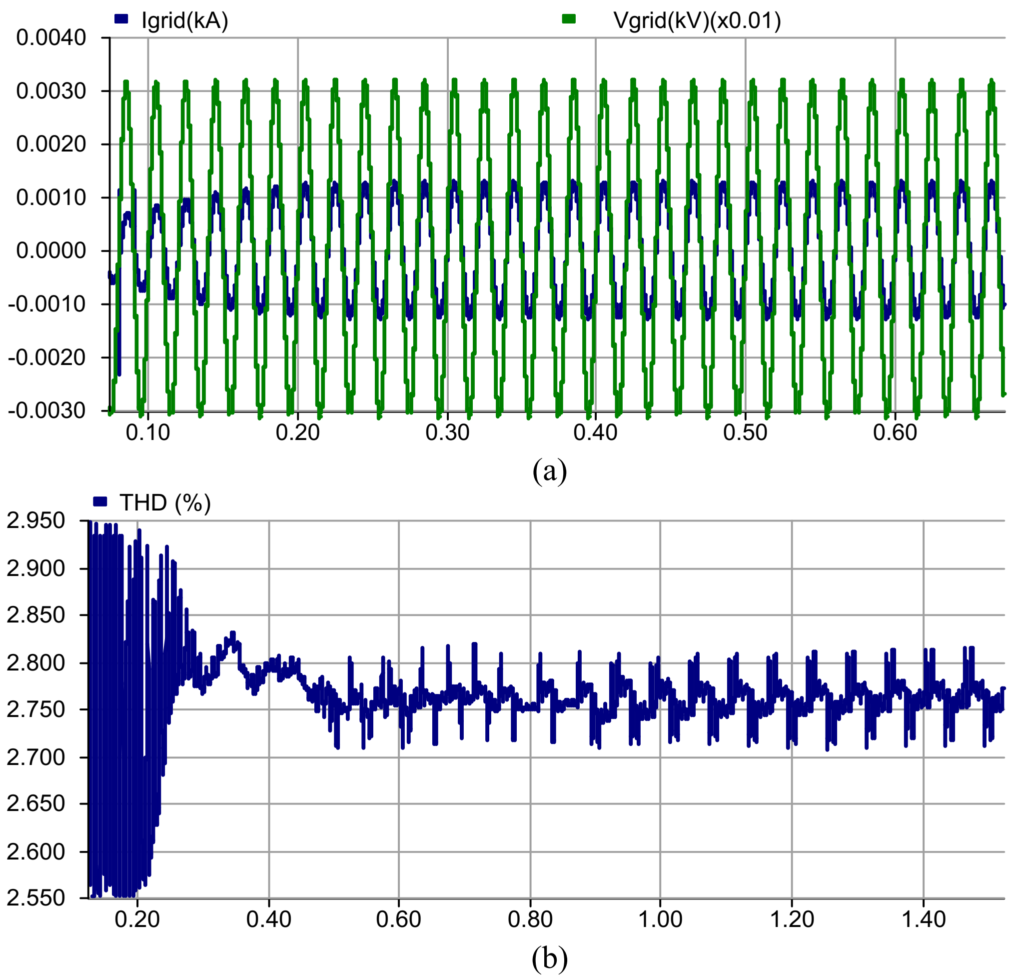


Figure 13. (a) Injected grid current (b) Grid current THD

Conclusions

In this paper, a rigorous model of single-stage flyback MI is simulated by using an electromagnetic transient software package PSCAD/EMTDC. A design procedure is highlighted for construction of an optimal single-stage flyback MI. The designing equations and controller structure are also provided. The system is analysed on a model designed 30V input PV voltage, 205 W maximum power rating, and 220 V_{rms}, 50 Hz utility grid voltage. The results demonstrate a close agreement with the design values. The simulation results show an efficiency of 91.9% for a 205W single-stage flyback inverter. From the results, it can be clearly said that single-stage flyback MI operated in DCM mode is a feasible solution for low power applications. In addition, simplicity of the controller structure related to utilisation of constant switching frequency and being easy to stabilise the control loop makes the system more attractive. The only drawback of the presented topology is its short lifespan due to the value of the decoupling capacitor.

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Renewable Energy Solutions for Sustainable Fishing Practices and Improved Livelihoods of the Fisherfolk in the South West Coast of India

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Abstract
This paper looks at the application of renewable energy solutions for sustainable fishing practices and improved livelihoods of the fisherfolk in the south west coast of India. This region is featured with the indigenous coastal community which is known for their traditional and sustainable fishing practices. At the same time, they are considered to be one of the most economically deprived communities. This is mainly because limited fish catch and the increasing operation cost that creates financial instability. The current practices of fishing methods highly depend on the diesel and the existing study results suggesting 70% of the total expense is spent for voyage alone. This leads to increased financial burden on the fishermen as well as generating an environmental problem in terms of increased carbon emission and pollution. In this context, the study is focused upon critical analysis of the usage of solar panel on fishing vessels that are used for the pilot project previously and its techno financial analysis. The data were collected from the fisher folk through interactions with them in their livelihood areas and secondary data from the peer reviewed sources. The results show solar energy could effectively reduce fuel consumption and improved economic efficiency. However, the pilot project could not continue and extend to many areas as the capital investment was high and limited financial support. The study recommends a new model of integrated solar and conventional fuel model and policy framework to include a financial model reducing the primary cost burden on the fisherfolk.

Keywords: Renewable Energy, Solar, Fisherfolk, India, Policy

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Introduction

The south west coast of India is known for marine friendly and sustainable traditional fishing practices (Panipilla & Dr. Johnson Jament, 2017). Fishermen from the districts of Trivandrum (Kerala state) and Kanyakumari (Tamil Nadu state) in South India are unique for their fishing skills and associated traditional knowledge incorporated with modern technology. However, the recent tropical cyclone disaster Ockhi had exposed their socio-economic vulnerability to the rest of the world through media reports and social media attention (Patil, 2018).

The fishing skill and these fishermen's hard work do not reflect on their socio-economic status due to various reasons such as economic habits like spending and saving, lack of technology, marketing constraints, exploitation of the middlemen, lack of investment from successive governments and similar other issues (Sarkar, 2012). Depleting fish resources and increasing operational cost make their livelihood much more difficult to sustain. Climate change conditions, warming in the Arabian ocean and Indian ocean, destructive fishing practices at the shore and marine pollution (Cinner et al., 2012) have forced the fish wedge to migrate towards further deep into the Indian ocean. As a result, the voyage time and operating cost is increased and the fishermen are forced to go to deep sea for venturing their fishing expeditions. This leads to the diminishing of earning capacity and hence a financial difficulty in the community, makes them depended upon external sources of funding for their survival.

Under these circumstances Association of Deep Sea Going Artisanal fishermen (ADSGAF), a fishermen organization based in Kanyakumari District, Tamil Nadu, India has launched a mission to introduce solar panels on fishing vessels to reduce the fuel consumption in the year 2010. Four years later in 2014 their first batch of solar panel enabled deep sea fishing vessels were launched as a pilot project (Suchitra, 2015). The project was widely celebrated and its results were positive on the fishermen's edge as the solar panels could substitute all their auxiliary power demands. Before the introduction of solar enabled lighting system, fishermen used to run main engine to get light during idle times (mostly during fish catching time) which causes huge waste of fuel. According to an estimate, the fuel consumption for auxiliary power demand is about 30% of the total fuel consumption (Babu & Jain, 2013). This suggests that the solar energy could save 30% of the total voyage cost which would be ultimately benefitting the fishermen. At the same time, it is important to acknowledge that there is no adequate legislation or policy interventions addressing offshore practices as well as limited financial support to the project. Meanwhile private companies had introduced auxiliary generators which are converted bike engines whose life cycle has already ended and price is one tenth of the initial cost of the solar module. As there were no financial supports for solar modules, fishermen went with the use of auxiliary generators where primary investment is comparatively less. In addition to this, it was found that there was no awareness or policy framework to make the customers understand the long term financial and environmental benefits of solar power.

Under these circumstances in 2018 Travancore Marine Corporation had started to revise and analyse the technical challenges, policy frameworks, financial assistance and way forward to make the marine fishing sector energy efficient and less carbon emitting. This is also in line with enabling to meet the intended nationally determined contribution (Union Environment Ministry, 2015).

Analysis

It is reported that in the south west coast of India especially Kanyakumari district has 1050 (Bino, 2015) deep sea artisanal fishing vessels. They are mechanized fishing boats and are capable of voyage more than 30 days in the deep sea. However, they do not use destructive fishing method like the deep-sea trawling vessels. Their primary and main catching method is hook and line fishing which is arguably the most sustainable type in the world as this method do not catch juvenile fishes and destruct fish habitats like reefs. For the artisanal deep-sea fishing vessels, the main power requirements are for propulsion and auxiliary power demands such as lighting and charging. The size of the boats usually starts from 50 feet length to 60 feet length. Depending upon the size and weight carrying capacity of the vessel, the fuel requirement for the propulsion varies. The interview with fishermen demonstrated that the fuel consumption of the existing engines varies 1 liter of diesel to 2 liters of diesel per nautical mile. The total diesel consumption goes up to 8750 USDper annum and above depending on the voyage distance. Wide practice among boat operators where they used main propulsion engine to light and charge devices even during idle hours which itself consumed around 30% of the diesel fuel. Then the ADSGAF intervened at 2010 and installed solar panels on the top of the boats as a pilot project. This was the preliminary attempt to make fishing vessels energy efficiency. Four solar panels of 250 W capacity each were installed on the top of the wheel house with a maximum capacity of 1KW connected with inverter and battery. The entire module was enough to satisfy the auxiliary power demands. Whilst adopting hook and line fish catching the fishes are caught at night time and fishes have to be separated from the hooks manually. The solar powered lights were helpful for the fishermen as cited by the previous pilot project head Vincent Jain. It had increased the efficiency and reduced the accidents usually happened to the fishermen while removing fish from the hooks at dim lights. The overall cost of the module was reported to be around 4350 USD(Babu & Jain, 2013) at 2013. It was subsidized by various agencies and funds were provided to the pilot project. Here came the challenge of financial viability of the project. As it was a pilot project and completely funded, fishermen whose boats were included in the project had to pay nothing. Hence there was no financial model or repayment system to expand another fishing boat. Considering the huge primary investment cost of the module, the boat owners were not ready to install the solar module on the vessels despite knowing the benefits of it. Here came another turning point in the sector when the old bike engines were converted to generators and supplied to the vessels as auxiliary generators at cheaper cost less than 300 USDwhich is less than one tenth of the total cost of the solar module. These petrol fuel run auxiliary generators had reduced the potential market of solar modules in the sector. It is also important to note that the carbon emission that could be reduced by solar modules per year is 19500 kg CO_2 per year per boat (Babu & Jain, 2013) . Despite being a climate change combat technology there got no policy interventions and financial supports. Before going to the next level of study into artisanal deep-sea fishing vessels' energy efficiency and its future, it is important to understand the possible reasons behind the failure of solar module project and why it had not got enough acceptance beyond the pilot project phase.

The project was financially backed by National Bank for Agriculture and Rural Development (NABARD) and supported by Bay of Bengal project and implemented through the association of artisanal deep sea going fishermen. The fishermen got the solar module freely accessible and no cost involved in it. After 5 years looking at those solar panel fixed vessels it is understood that there was no technical follow up happened after the installation. However, there was no further development regarding market model. From the policy analysis point of view, it is important have a business model for the sustainable existence of the product in the market. However, considering the huge quantity of the market and the carbon reducing possibilities ADSGFA failed to take the pilot project forward. In this case, it was not followed green technology policy practices where government's initiatives to provide market assistance for the green technologies to compete with the conventional technologies, when they are introduced for the first time. Under the absence of green protocols in the marine sector, motor vehicle companies introduced cheaper auxiliary generators, which were converted two-wheeler engines whose life cycle has already ended. These engines were sold at a price one by tenth of the initial cost of the solar module units. Considering efficiency and emission of outdated generators, it is important to understand in a macroscopic view point that the economic and environmental impacts produced by them are very high and underrated by the responsible climate action agencies. It is very disappointing fact that neither climate change action policies nor responsible government sector took the artisanal marine fishing vessels accounted in their action plans and visions.

Now looking at the technical side of the project there would be more revelations on why the model didn't sustain in the market.

- The SPV panels were mounted on top of the wheelhouse with maximum power production of 1kWp. Total cost of the system to the end customer was3650 USD.
- The fishing boats remain idle in mid sea at night during fish catches, when lighting is required to attract fish. The stored solar power will take care of the energy requirements during this time for about 3 – 5 hours. Saving about 30 liter of diesel every day. (Babu & Jain, 2013) Mounting the panels elsewhere will affect their stability at the violent sea. It is also a cause of discomfort for the untrained artisanal fisherman hindering their movement on the boat.
- Most of the technical and economic advantages were nullified with the introduction of altered motorbike engines as power generators in fishing boats for auxiliary power supply with petrol as its fuel. Their capital cost was much lesser (approx.300 USD), required little maintenance and can run on a liter of petrol for a single night.
- After the installation, no technical feedback or follow up was undertaken due to which there is very little data about the success of the project. Moreover, only one boat fitted with SPV modules is operation now.

Case Study

For the case study an artisanal fishing vessel from the district of Kanyakumari, Tamil Nadu. The dimensions of the vessel are as follows. Length 19.5-meter, breadth 5.57 meter and depth 3 meter respectively. It has a 6-cylinder 140 HP Ashok Leyland brand engine.
Fuel type- Diesel

Power Requirements – Propulsion and Auxiliary power demand
Number of voyage days- Average 30 days
Fuel Consumption – 1-liter diesel per nautical mile.
Auxiliary power consuming units - 5 units of 50W LED lamp, 15W LED tube light, charging units.
Cost Analysis -
Vessel cost- 87350 USD
Engine cost- 7280 USDAuxiliary power cost analysis

Table 1: Auxiliary power cost analysis (Source: Market interview)

Cost of auxiliary generator	20000 INR
No of auxiliary generators	2
Capacity of generator	750VA
Fuel type	Petrol
Working hours	5 hrs/ day
Total fuel consumption	1 liter
Total operational cost	1.15 USD/ day

Now consider two different auxiliary power generation cases; Solar and hydrogen fuel cell.

Capital cost of solar- 1460 USD/ kWp
Operational cost –30 USD/ year
Based on the auxiliary power requirement a comparison of possible fuel options was done. They are existing petrol generators, solar photovoltaics and solid oxide fuel cells respectively.
Power source comparison for 1KW auxiliary power demand

Table 2: Power source comparison for 1 KW auxiliary power demand (Source: Market interview)

	Petrol Generators	SPV	SOFC
Capex	450 USD	2200 USD	1460 USD(mass prod)
Opex	75 USD	30 USD	45 USD
Life	3 yrs	15 yrs	20 yrs
Fuel	Petrol	Nil	Natural gas
Maintenance	High	Low	Low
User friendliness	High	Average	Low
Impact on environment	Pollution,Leakage	e-waste	Very low, Rare earths

It is understood from the comparison that petrol generators are cheaper and user friendly but highly polluting. Where as solar photovoltaics have high capital cost but operating cost is very low. Solid oxide fuel cells are very promising but for the time being they are futuristic technologies.

Considering all these conditions, SPV power systems for auxiliary power supply in fishing boats is not viable in technical as well as economic terms. Based on these understandings, energy requirements problems of fishing vessels require a fresh approach. Data from on field observations and deploying a questionnaire had helped to understand the areas which interventions are required.

The main areas identified where absence of proper freezing technology in the artisanal deep-sea fishing vessels and conventional IC engines mostly refurbished from heavy automobiles. Each area is separately addressed in the below session.

Freezing units: At present the freezing method practiced is primitive method of stacking fish and ice in multiple layers. They usually carry 400 to 900 blocks of ice where one block is 60Kg and costs1.15 USD. It is important to consider the fact that the average voyage time is 30 days in which minimum ten days are required to travel back after the catching of fish. The quality of the fish reduces in this method and the income reduces considerably. It is understood that to preserve the quality of the caught fish it is important to freeze it between -2dgree Celsius to – 20 degree Celsius (Heen, 1982).

Engines: They are mostly refurbished engines of capacity ranging from 140 HP to 450 HP. These engines are poorly maintained and polluting marine environment.

Now considering the above-mentioned two factors an analysis for freezing unit on an average sized fishing vessel was done and the observations were as follows.

- Maximum SPV module possible - 2kWp, due to structural constraints and working space for an average of 10 workers on board each vessel.
- Freezing requirement – 8 (5ft X 5ft X 4ft) compartments to freeze about 20-ton fish. Each compartment will draw power to the tune of about 500W with total power drawn 4kW at full capacity.
- The alternator coupled with the engine has to be replaced to deal with the extended power requirement of the freezing unit.
- Engine should be continuously tuned ON during the entire voyage to keep the fish at the required temperature till it is taken for processing. This will be an extra burden as additional fuel cost.
- Powering the freezing unit with solar power is practically impossible. Using batteries to power the unit to remove the load from the engine is extremely ambitious considering the volume and weight of the battery pack.

Conclusion and Way forward

The deep-sea artisanal fishing sector falls into the categories of sustainable transportation, livelihood and behavioral patterns. It requires an interdisciplinary and multidimensional approach to deal with the sector. It is understood from the above-mentioned studies that the existing working model of solar photovoltaics (used for the auxiliary power demand) are not technically and financially feasible for the fisher folk. Due to spatial constraints there can't be installed adequate number of solar panels on the top of vessels to meet all the power requirements. In a comparative analysis it is found that fuel cells are promising and has a future in the sector when mass production begins. The next important and most crucial aspect is the introduction of a scientific freezer technology. As of now main propulsion engine can be the only source of power for the proposed freezer in the vessel. But step by step interventions with new technologies can reduce the excessive dependency on conventional fuel as a result of the introduction of freezer in the vessel. As a beginning phase changing materials shall be introduced in the freezer so as to reduce the power consumption. It is important to introduce a cold chain network for the fishing sector of India and the pilot project shall be tested at the south west coast of India.

Unlike the agricultural sector the fishing sector requires off shore technologies as well while designing the cold chain network. Thus, the preliminary stage if the cold chain network begins from the fishing vessels and extends to the landing centers and supply chain etc. Phase changing materials incorporated freezers which consume power from renewable energy sources such as solid oxide fuel cells would create a promising future and potential carbon emission reduction. Since the total number of mechanized vessels in the Indian shores 58911 (Mohamed, 2015) the collective potential of the sector to contribute national determined contribution is considerable. Besides the green technology intervention improves the livelihood of the fisherfolk and act as a catalytic agency in the mission of protecting the ocean and attaining the United Nation's sustainable development goal 14 which is connected to life below water. This project can be integrated to the UN mission of Decade of Ocean Science for Sustainable Development.

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Electricity Generation from Renewable Sources: Algeria Cases (Situation and Prospects)

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Abstract
The world is witnessing fast population growth. So, life needs are increasing especially, energy which is considered nowadays, as the sinews of life and the decisive factor in economic growth. Fossil energy is the most widespread and exploited, because it is the mainstay of economy of the most countries, the producing countries. However, all countries are worried about the danger of energy depletion on the one hand. On the other hand, fossil energy is the main cause of environmental pollution and global warming due to waste gases. The volatility of oil market and its impacts on world economy drive all countries to seek for another alternative instead of fossil energy to world needs in all aspects of life, mainly electricity generation from renewable energies. Algeria may play a role in this future, a major role in field of renewable energies because of diversity of its natural resources. This research aims at diagnosing the world renewable energies exploitation, as well as highlighting the renewable energies position in Algeria while referring to Algeria's efforts in this field, the study results show that Algeria possesses high potential in the field of renewable energies, in addition to political efforts tending towards reinforcing and developing renewable policy. However, generation of renewable energy represents only 5.5% of total fossil energy. This ratio is still low in comparison with Algerian energy potential. As a result, Algeria has little experience in renewable energy technologies because it relies on fossil energy and well-mastered techniques.

Keywords: renewable energy, fossil energy, electricity generation, renewable energy policy, Algeria.
Jet classification: Q20, Q35, Q48.

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I. Introduction

Fossil energy, since its discovery in 1859 until the 21st century, continues to be the primary source of energy, because of its important and vital role in the economies of all countries. However, this fleeting energy has become the main cause of environmental pollution as well as the increase of global warming.

Due to the adverse effects of the oil industry's activity on the environment as well as the increased economic crises caused by the multiple fluctuations in oil prices since the 1970s to date, sometimes in declining, sometimes in increasing The average price of oil reached $43.73 in 2016 against 109.08 in 2013(Global.B.P, 2017), a decrease of 40%. These factors have led the international community and energy conservation experts expecting other sustainable alternatives to the environment through energy conservation experts to look for other sustainable alternatives to the environment, through the International Energy Agency created in 1974. The major concern of this community is the technological and economic strengthening of renewable energy such as solar and wind energy and other energy as an ideal solution for the alternative to fossil fuels.

At the climate conference, COP 21 in Paris 2015, COP 22 in Marrakech 2016, COP 2017 in Bonn. More than 190 countries agreed in Paris to reduce global warming to over 200 degrees Celsius, with the goal of minimizing global climate threats. Renewable energy is one of the most important tools to combat this climate change through the development and encouragement of rich countries as major investors in this field, aiming to provide their financial support to poor countries and owners of natural resources such as African countries. An amount of $100 billion per year concluded for their injecting in the climate budget of Cop21 until 2020. (Hirst, 2015)

Renewable energy may not yet be a substitute for fossil fuel because of its multiple derivatives, but its growth in recent years thanks to technological progress gives it a clear competitive advantage in the global energy market. Governments and the private sector have started to injected billions of dollars into the still-nascent market, such as China, which reached more than $103 billion in renewable energy investments in 2015(Buckley & Nicholas, 2017).

Europe has become a successful European model in this field as the most innovative and efficient sector. In 2015 in Germany, the percentage of electricity consumption generated by renewable energies reached 32.5% against 6.5% in 2000(Pescia & Energiewende, 2016), and which thrived further afterwards and the global investment in renewable energy in 2016 was about 241.6 billion dollars(J. Sawin, 2017).

Investment in the renewable energy sector considered a purely economic investment. The expansion of renewable energy industries has led to the decline of renewable energy technologies and the growing development of emerging economies as well as the evolution of new jobs. In 2016, renewable energy sources supported around 9.8 million jobs(J. Sawin, 2017), and 5 million hobs in 2011(J. L. Sawin et al., 2012)

Algeria, one of the oil- producing countries since 1958, a member of OPEC in 1969, classified 18th in 2015 in the world oil production through the Sonatrach company and 3rd producer in Africa. With a production of 671 barrels/ day in 2015, or 19% of African production against respectively 27% and 22% for Nigeria and Angola(Mouissi, 2016).Despite these characteristics cited, Algeria is one of the developing countries, investing in the field of RE. The year 1982 was the birth of high commissioner of RE conservation; its main task was the establishment of the infrastructures to start its activities. Five development centers and pilot stations have emerged afterward. Their purpose was and still to provide the scientific, technological and industrial databases of the RE development program. Algeria aims to generate about 30% of electricity from renewable sources by 2030(CDER,1990).

By its geographical position, the area of Algeria is the largest in Africa, with 2.381.741 $km^{2,}$ four times France and 60 times Switzerland, with many forests in the middle, however, the Sahara alone represents 84% of the territory. In addition to fossil energies, Algeria as well holds several sources of RE; sunshine throughout the year, considerable winds speed in the highlands, significant water resources. All of its natural energy qualifications make it one of the leading developing countries in the investment of energy's sustainable. By what was mention above, the problematic of this study comes as follows:

What is the current and future renewable energy policy in Algeria and what are its capabilities? Followed by these secondary questions:

1-Owning potential renewable resources will allow the development of RE production?
2-Owning RE technologies will allow the evolution of cleans energy production?
3-Owning fossil energy and mastering its technology can promote its own production of clean energy?

II. Methodology

This paper is based on works in terms of articles and books on the subject of the same theme, which is **"Electricity generation from renewable sources"**, joining this to the most credible statistical journals via their websites in the field of energy studies such as:
1-A.Boudghene Stambouli,& all, a review on the renewable energy development in Algeria: Current perspective, energy scenario, and sustainability issues, Renewable and Sustainable Energy Reviews 16 (2012): This article demonstrates the fundamental priorities of Algeria to use several renewable energies sources and environmentally friendly energy conversion technologies. It has shown as well that Algeria is endowing with large reserves of energy sources, mainly hydrocarbon and considerable potential for the utilization of RE sources especially with respect to solar energy. This document develops the RE potential different from Algeria targeted by the Ministry of Energy and Mines (MEM) according to the strategic plan which aims to reach 40% of RE (mainly solar) share in the production of electrical energy by 2030.
2- Journals (Ministry of Energy of Algeria, Algeria's RE centers reports (CDER), Arab future Energy Index AFEX 2016. the article is endowed with various statistics

from journals renowned at the international and national levels for renewable energy during the period of 2011 outlook to 2030.

III. Discussion and result

III.1 The production structure of electricity in Algeria and the role of renewable energy sources (reality and future)

III.1.1 The Algerian sustainable energy resources potential: Algeria is a country with a huge potential and varied in RE energy, it holds in(Semrouni, 2007):
1-Solar energy: 3600h of sunshine a year;
2-Wind energy: between 3 to 6 m/s;
3-Geothermal energy: 200 hot water springs in the north of the country (between 45° C and 98° C);
5-Biomass: 37 MTEP for forests, 30MT for urban waste;
6-Hydroelectricity with a potential 1500 GWH (with 6% of current electricity generation capacity).

III.1.1.1 Solar energy

Solar energy is one of the most important sources in Algeria, providing one the highest solar potentials in the world, with 86% of the national territory in the desert region (the Grand Sahara), Algeria holds between 2500 and 3600 h of sunshine a year. The average solar radiation in Algeria generates about 200 kwh/m^2, which is twice the radiation generated on the European continent(Grigorjeva, 2016), see figure1. The energy absorbed daily is on horizontal surfaces of 1m^2 is 5 kwh over the major part of the national territory or about 1700 kwh/(m^2 year) for the north and 2650 kwh/(m^2 year) for the south of the country see table 1(Missoum, 2015):

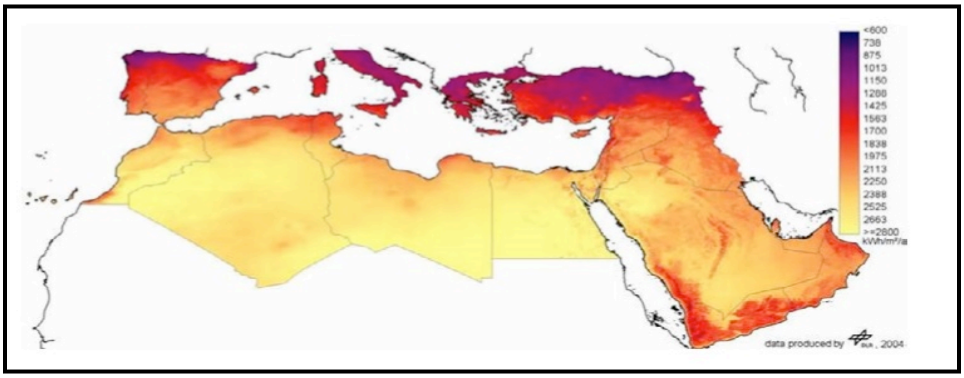

Figure 1 Geographic map of Algerian solar energy

Region	Coastal	High plateau	Sahara
Surface (%)	04	10	86
Average duration of saneness per annum (h)	2650	3000	3500
Average energy received (kwh/m^2 annum)	1700	1900	2650

Table 1 Solar potential in Algeria

III.1.1.2 Wind potential

The vast geographic of Algeria is divided into two regions, the north, and the south. A mountainous relief characterizes the north; however, the southern region is endowing with wind energy as mentioned in figure 2. They are particularly located in the region of Adrar in the southwest notably, with 4 m/s and more than 6m/s (Guerri, 2008) as well as Oran in the northwest, expanded from Meghress to Biskra in the east and from El Kheiter to Tiaret in the west. A number of sites along the coast have average wind speeds above 5.0 m/s, rising to over 8.5 m/s at 80m as seen in figure 3. This wind energy potential is ideal for water pumping especially in the high plains(Stambouli, Khiat, Flazi, & Kitamura, 2012).

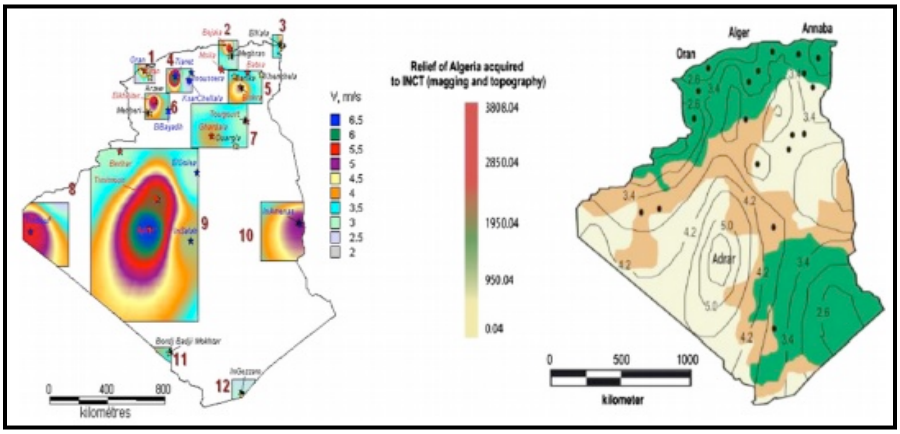

Figure 2 Wind chart of Algeria. Left: identified windy sites, Right: topography of the identified sites

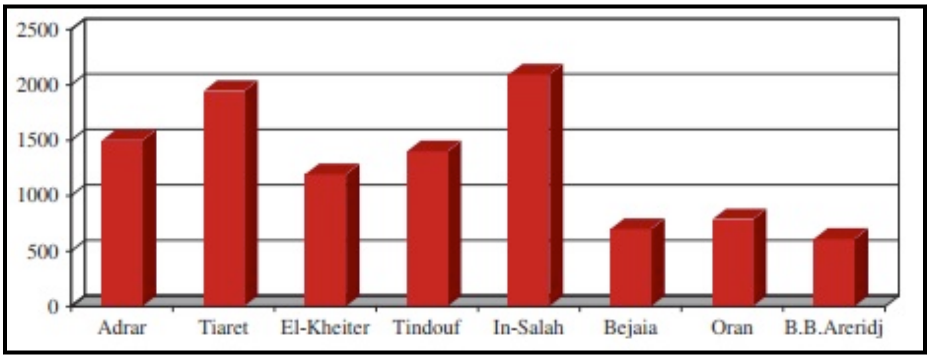

Figure 3 Average power output in the eight identified wind places.

III.1.2 State of renewable energy in Algerian energy policy

From the point of view of the legal framework, institutions, and programs in RE:

III.1.2.1 The legal framework

In the RE framework of the development of investments and technologies, the Algerian government has promulgated laws and regulations in this direction, several economic devices, organizations, and institutions were created to promulgate technical facilities able to develop the renewable energy technologies such as (CDER) and (FNER). These laws(ME, 2016) and its institutions are represented in table 2 as follows:

Year issued	Law N°	Subject & content
July, 28, 1999	N°99-99	Control of energy
February, 05, 2002	N°11-02	Electricity and Distribution public gas channels
August, 14, 2004	N° 09-04	Promotion of capacities in the context of sustainable development
December, 30, 2009	N°09-09	Bearing of finance law for 2010 including its article 64 establishing the national fund for renewable energies and cogeneration (FNER)
July, 18, 2011	N°11-11	Including the Supplementary Finance Act 2011, noted the level of tax revenues which finances the National RE Fund and the expansion of the National Fund and the expansion of the field applied to cogeneration plants.
December, 20, 2014	N° 14-10	Bearing the Finance Act of 2015, Article 108 provides for the merger of the tow special funds "the National Fund for the Control of Energy (FNCE/FNME) and the National Fund for RE and Cogeneration (FNER).
2017	-	Introduction of the energy efficiency tax which contributes to the improvement of the National Fund for the Control of RE and Energy Cogeneration.

Table 2 Algerian Legal Text of RE

III.1.2.2 Algerian institutions of RE

The laws and decrees mentioned above have allowed the creation of the creation of several governing institutions in the field of RE:

RE Institutions	Year created	Their
1-Silicon Technology Development Unit (STDU) (Abderrahmane, Mghazi, 2018)	1988	Development of silicon technology, -Conduct scientific research and technological innovation, -Training for post-graduation in the shops of science and semiconductor materials and devices for applications in several fields such as photoelectric energy storage. This unit also contributes with the cooperation of several universities in Algeria,
2-Centre for RE Development (CDER) (CDER,2017)	March, 22th, 1988	-Collect, process and analyze data for accurate assessment of solar capabilities, wind/ geothermal and biomass; -Responsible for conducting research and development programs, scientific and technological of renewable energy

		systems. -Formulation of necessary research work and development technical procedures, physical equipment and means of measurement necessary for the exploitation of RE.
3- Solar Equipment Development unit (CDER, 2017)	By decree N°008 January 9, 1988 by the presidency of the Republic (Official Gazette N°06, February10, 1988	-Design and optimization of RE for the production of heat, electricity, cold water treatment; Implements studies and research development of technological processes prototyping and pilot production; -Realize technical-economic and engineering studies to set pilot installations to insure the transfer and the master of new technologies; -Define characterization techniques, test, quality control and compliance to insure qualification, approval and certification of developed equipment's. -the development of solar equipment, in particular the film with economic and engineering technical studies; -the completion of some prototypes and experimental production of solar, thermal and photoelectric equipment and some mechanical thermocouples.
4-RE Applied Research Unit (URAER), affiliated to the (CDER)	1999	-The national effort for research and training. Thus, by collaborating with universities and other research center; -as well as with the possibility of providing within the unit a training of quality in renewable energy starting from master level to the specialized PHD.
5-Financial incentives, it's National fund for RE and Cogeneration (NFRE/FNER)(Maged et al,. 2016)	In 2000 under law N°2000-116 to finance energy efficiency projects	-Encouraging clean energy propjets by financing them
6-RE Research Unit in Saharan Area (URERMS) (CDER,2017)	With Ministerial order N°76 of the May, 22nd,2001 at the level of the CDER	-Collect, exploit, process and analyze the whole necessary data for a precise evaluation of solar, wind and biomass energy in Saharan regions; -Operate scientific and technological works on the design and development of devices and equipment's for solar and biomass energy packaging; -Proceed to study the qualification and the

		adequacy of settlement tests, observation, experimentation, exploitation, measurement, reliability and endurance of solar and wind energy equipment, -Launch production and biomass valuation activities for energetic, environmental and agronomic purposes.
7-New Energy Algeria (NEA), created by two major players in the Algerian energy sector, namely the Sonatrach and Sonelgaz (CDER,2017)	In 20002	-The promotion and development of new and RE, -The identification and realization of projects with high technological value added new and RE; -The creation of a center of excellence dedicated to research and development (R&D) and training in the field of RE; -The development of win-win partnership, as part of the technological collaboration; -The consulting with national and international companies.
8-Centert for Research and Development of Electricity and Gas (CREDEG)	January, 1st, 2005	-the production, transmission and distribution of electricity, -pipeline transportation and distribution of gas, -The promotion of new and renewable energies, -Qualification of materials and equipment Electricity and gas. -Consulting and technical support, demonstration and certification, in the field of industrial electricity and gas; -Adoption of electricity and gas devices used by the local consumer; -State the means and equipment electrical and gaseous; -Introduction of new technologies and research technologies through applied and experimentation; -Development and promotion of the use of RE the targeted objectives of (CREDEG) are: -The safety of people and equipment goods, -Environmental protection, -Continuous improvement of the technical performances of the installations by the development of innovative solutions to the technical problems inherent in the development of SONELGAZ's business activities.

Table 3 Algerian institutions of RE

III.2.2.3 The national program of RE since 2011 outlook to 2030

Algeria has also developed an ambitious program for the evolution of renewable energy and efficiency since 2011 through their institutions and centers mentioned before. This program is defined for the different phases as follow:(MEM, 2012):
-2013: Planned to install a total capacity of around 110 MW;
-2015: A total power of nearly 650 MW should be installed;
-2020; An installation is expected to have a total capacity of approximately 2600 MW for the domestic market and an export opportunity of the order of 2000 MW;
-By 2030: Planned to install a power of nearly 12000 MW for the domestic market as well as an export opportunity of up to 10000MW.

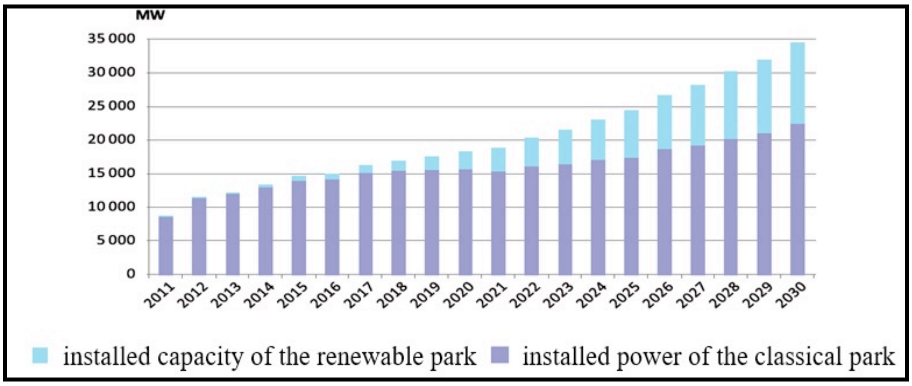

Figure 4 Structure of the national production park and outlook to 2030.

The aim of this program is to ensure the availability of 40% production on RE by 2030. The program focused on the development of wind, solar photovoltaic and thermal energy. The solar energy (PV and thermal) will present the largest source of clean energy production in Algeria with a rate of 60% of total production 2030 according to the objectives of the project shown in figure 5.

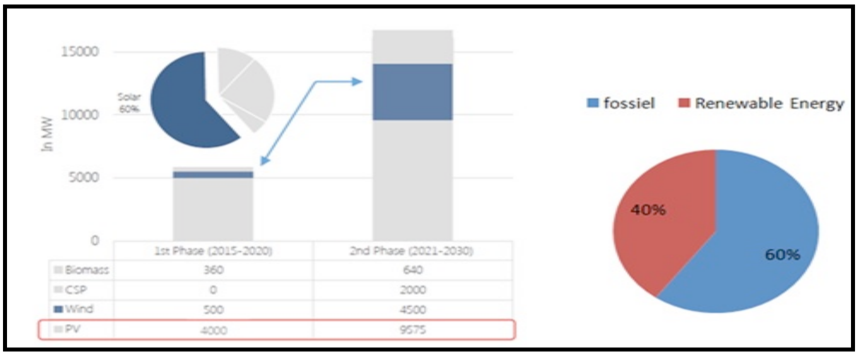

Figure 5 New RE program the year 2030.

The vision of the Algerian government is based on a strategy centered on the RE production of 22 GW in outlook 2030(Bakli & Tell Group, 2016), as mentioned in table 4.

Initial Renewable Energy plan	2030 Targets
Solar PV	13.5 GW
Solar CSP	2 GW
Wind	5 GW
Biomass	1 GW
Total	**22 GW**

Table 4 Initial RE plan 2030.

III.2 State of projects electricity generated by RE in Algeria

III.2. 1 Installed renewable power capacity evolution in Algeria from 2000 to 2017

Electricity production in Algeria is predominantly dependent on fossil energy, especially natural gas, contributing with 94.5% in 2010, followed by 5% hydropower and 0.5% of solar energy (League of Arab states, 2010). As shown figure 6, over the past decade, a reducing 93% recorded in 2015 in the generated electricity dependence by gas either a decrease of 1.5% replaced by 3.4% in RE production.(Grigorjeva, 2016)
The below figure shows that there is a trend towards diversifying the sources of electricity generation by focusing on other sources of RE, other than hydropower, especially wind energy and solar energy.

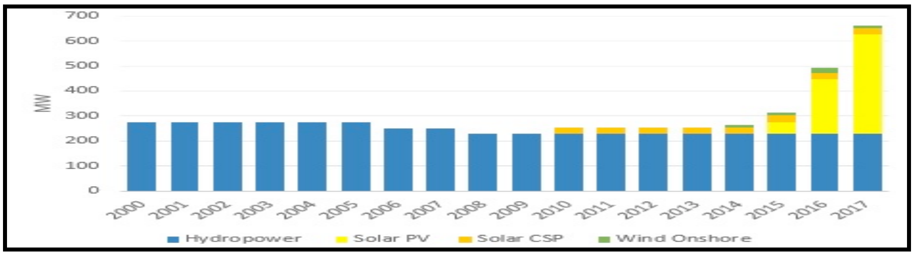

Figure 6 Installed Renewable Power Capacity in Algeria (2000-2017)

-For the solar energy: it was only in 2011, where exploited the solar energy as a sources of RE in Algeria, although Algeria has one of the highest solar potentials in the world with 86% of territory covered by the Sahara desert. Algeria provides for 25000 to 3600 annual sun hours, the corresponding average solar radiation equals to 2000kw/m^2 (Grigorjeva, 2016)
-For the wind energy: energy has entered into use as of 2014. Following the five-year plan (2010-2014), focusing on supporting the activities of local wind power units.

A 50% integration rate is the objective to attain for the 2014-2020 periods. This period will be marked by the following action(Stambouli et al., 2012):
-Development of a wind tower and turbine rotors production plant;
-Promotion of a national subtracting network for the manufacturing of the nacelle equipment;
-Development of engineering activities and design, procurement and construction capabilities to enable Algerian companies to achieve an industrial capacity rate of at least 50%.

III.2.2 RE Production in Algeria in 2017 and Installed Capacity

III.2.2.1 RE production in 2017

Figure 10 showed that during the year 2017 Algeria installed about 435.2 MW RE capacities with an increase of 37.55% compared to the year 2016, distributed as follows:

-425 MW generated from solar energy representing 64.10% of the total RE, where 400MW generated by PV solar capacity and 25 MW generated by concentrated solar power capacity (CSP);
-10.2 MW wind power capacity, representing 1.5% of the total RE.

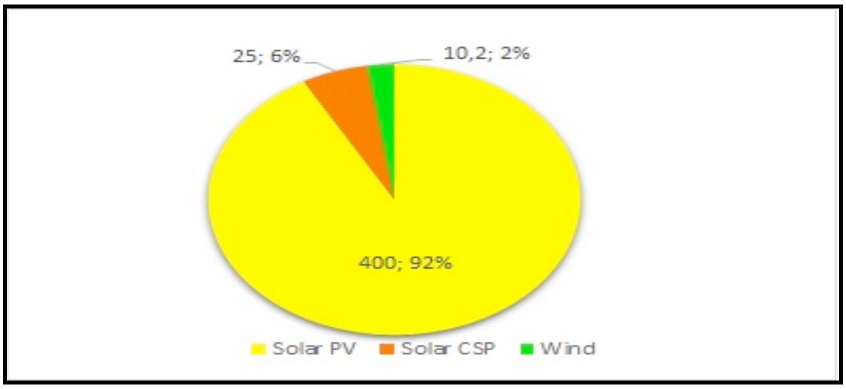

Figure 7 renewable energy production estimates in year 2017.

III.2.2.2 Installed Capacity

These capabilities distributed throughout the national territory. As showed figure 8, Algeria has used all of its territories for the installation of RE projects, whether to the north, south, east or west. Although Algeria was suffering from an economic crisis due to mow oil prices, during the period 2014-2015, who reached in the $40.68 (Boudia et al., 2017). This has led Algeria to apply economic austerity and political freeze leading the delay and the abolition of some projects programmed into RE.

This explains the delay in 2015 in the realization of 652 MW of RE projects, by the achievement; only of 435.2 MW in 2017 is a delay of 214.8 MW such as Guelma's projects geothermal power, Khenchela's wind power. Other projects have been delayed in the application such as SPP II in Elmeghier & SPP III in Namaa, SPP IV in Hassi Raml and others have been totally canceled like the Desertec project as mentioned in table n 5

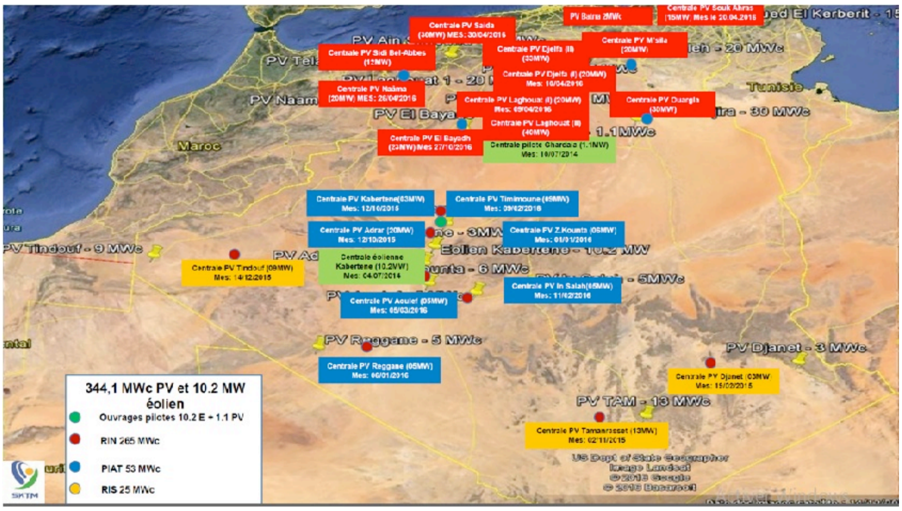

Figure 8 all RE Capacity Installed in Algeria in 2017.

III.3 Cancelled RE projects

We expose the projects launched but cancelled afterwards. This explains the main cause of the delay of the objectives announced by the Algerian government, to generate 650 MW of RE projects in 2015. Table 5 summarizes these projects. The table below clearly shows the many projects that are beings completed, but with a delay in implementation, this has led to the interruption of the Algerian state's objectives in this energy field. In addition, there are projects that have been cancelled in this area including the Desertec project that could have brought Algeria a very important economic wealth with a solar energy production capacity of 20 GW in the year 2020 and 100 MW for the year 2050. The reason for the abandonment of this project is due to its high cost, which coincides with the austerity policy imposed by the Algerian government. This termination allowed Morocco to adopt this project.

	Projects under construction & planned for construction & which were canceled			
	RE Technology – Projects	Places	MW	Established by
planned for construction				
2012	SPPII	Elmeghier (eloued)	80 MW	Public sector
	SPPIII	Nama	70 MW	
	SPP IV	Hassi Raml	70 MW	
	Eloued	Eloued	150 MW	
Projects under construction				
15/10/2012	Construction of a renewable plant one station for the solar PV.		7 MW 2 MW	Signed between Algeria signed between Algeria and Germany

2014	4 stations for the production of solar electricity	Saida	30 MW	German company & NERA
		Naima	20MW	
		Elbaid	23MW	
		Sidi Bellabs	12MW	
2016	Series of 6 projects Algerian solar thermal plant	Sahar & south west & Great Algerian south	1350MW	-
2020	27 new projects of the PV sector	most important plant in Dejlfa	638 MW	German & NERA
	Geothermal Wind	Guelma Khenchela	5MW 20 MW	-
Project which were canceled				
13/04/2009	Desertec project	Sahara Desert	20 GW in 2020 100GW in2050	Algeria by Siemens Garman- canceled -

Table 5 RE projects under Construction & cancelled project

Conclusion

The article entitled electricity generation from renewable sources, Algeria cases (situation and prospect), has meant to answer the main question "**what is the current and future RE policy in Algeria and what are its capabilities?** The data of this research shows clearly the political will of Algeria to the encouragement of their own energy production supported by publication of several laws and legal decrees started by the law carrying the control of energy under n°99.99 of July 1999 followed by other laws until this day. This new energy policy has also allowed the creation of several institutions operating in the field of RE such as (CREAD, URAER, NEA) in order to implement the national program of RE- launched in 2011 outlook to 2030.

It reveals from this study that Algeria benefits thanks to its geographical location, from the climate point of view and territory, of great potential in RE focused on solar and wind energy. This advantage allowed it to be in 3rd place in renewable power capacities in Arab world after Morocco and Egypt. This observation makes it possible to respond negatively to the first secondary question, which states, "**effectively owning potential renewable resources will allow for the development of RE production".** In the case of Algeria, despite its RE potential; this advantage does not allow it to develop this field properly. RE production in Algeria, remain very modest, due to several reasons. A deficiency of mastery in RE technology. A lack of appropriate support for projects programmed in RE such as (SPPII, SPPIII, and SPPIV). a lack of political discernment to lead RE projects, a marginalization of human experiences in energy economy due to a gap of awareness of the economic and financial benefits in this field, as well as a limitation of the RE sector in a secondary branch at the level of the Ministry of environment and renewable energies.

The reasons cited above also makes it possible to respond negatively to the second question, that **“Owning RE technologies will allow the evolution of cleans energy production?”.** In the case of Algeria, its late master degree in RE technology did not allow it’s, to promote and develop this field such as developing countries, preferring to remain dominant in fossil fuel technology. As a result, this leads to negative answers to the third question that “**Owning fossil energy and mastering its technology can promote its own production of clean energy**”. Algeria is a country based economically on oil revenue, mastering the fossil fuel technology perfectly since more than 50 years of activity, it did not knew to exploit this advantage for the benefit of investment development in RE especially in the boom oil price’s period recoding more than $120/barrel. On the contrary, this advantage has weakened the political will in the investment of the projects in RE that needed an appropriate budget.

Despite the blatant delay of Algeria in the clean energy production dominated by fossil production, it nevertheless records a significant evolution of 187% in RE production with hydropower in 2017 compared to the year 2008, following the statistics of IRENA 2018. Notwithstanding for what has been developed, Algeria aims in the future by its geographical advantages and their potential in renewable energy in order to reach the objectives of the national energy program 2030, which aims realize 22 GW generated by RE representing so 40% of energy production.

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Resilience and the Threat of Natural Disasters in Europe

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Introduction

This paper focuses on the existential threat of natural hazards. History and recent experience tell us that the most constant, and predictable, hazard in Europe is that of widespread flooding with storms, often with hurricane force winds, slamming the coastal area and causing flooding inland as well.

The modern world is seemingly plagued with the scourges of the Old Testament: earthquakes, floods, tsunamis, volcanoes, hurricanes and cyclones, wildfires, avalanches and landslides. Hundreds of thousands, if not millions, have perished globally in natural hazards, falling victim to extreme forces of nature.

None of these perils are new to civilization. Both the Gilgamesh Epic[1] and the Old Testament talk of epic floods.[2] The Egyptians faced ten plagues. The Minoans, Greeks, Romans, Byzantines, and Ottomans experienced earthquakes, tsunamis, volcanic eruptions, and pestilence. A cyclone destroyed Kublai Khan's invasion fleet of Japan on August 15, 1281. A massive earthquake in Shaanxi Province, China on January 23, 1556 is estimated to have killed 830,000 persons.

A discussion of extreme hazards often involves a common misconception of 100 year floods, 500 year floods, 200 year returns, and similar periods. A mistaken belief is that a "100 year" flood only occurs once a century. The measurement period is a statistical average over an extended period of time. It is not a means of forecasting. It means that on average a storm of that magnitude will occur once in a hundred years, but these storms could be back to back. For example, the German city of Grimma was flooded in 2002 and 2013. Both events were "100 year" floods.[3]

"Extreme" natural hazards have always been with us. They are "extreme" for four reasons; they are often unforeseeable, frequently unavoidable, and perhaps only partially controllable.

The fourth reason is that they become extreme when they affect people. Nature has always had extreme forces, but little notice is taken of them until they substantially impact people. A major earthquake two centuries ago in the United States illustrates this reality.

The New Madrid Fault set off three earthquakes, centered in Arkansas, between December 1811 and February 1812. The earthquakes were so intense as to set off church bells on the East Coast over 1,000 miles away. The damages today would be

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1 Center for Online Judaic Studies, Gilgamesh Epic: The Flood Story, http://cojs.org/gilgamesh_epic_the_flood_story/.
2 Frank Lorey, The Flood of Noah and the Flood of Gilgamesh, http://www.icr.org/noah-flood-gilgamesh/.
3 News: German and Dutch river flood benefits from more mum, less dad, Feb. 10, 2017, http://www.dutchwatersector.com/news-events/news/23386-german-and-dutch-river-flood-protection-benefits-from-more-mum-less-dad.html.

astronomical, but the vast area was sparsely populated without major structures in the early 1800's.[4]

Two natural disasters in the 17th Century during The Age of Enlightenment set the stage for discussing today's natural hazards risks both in Europe. The first, the Great London Flood of 1703, was of meteorological origin. The second, the Great Lisbon Earthquake of 1755, was of geological origin. The earthquake and its ensuing tsunami and firestorm affected large areas of Europe and North Africa as well as reaching the New World.

The Great Lisbon Earthquake of 1755

Rousseau recognized the development and population hazards reality after the Great Lisbon Earthquake. The earthquake, estimated to be 8.5 on the Richter scale,[5] was followed by a fire and tsunami. Much of the city was destroyed by this horrific trifecta of perils with an estimated 60,000 fatalities.[6] Most of the city's churches were destroyed on All Saints Day, giving rise to the claim that the earthquake was an Act of God.[7] Portugal's Prime Minister, the Marquis of Pombal, ordered a study of the tragedy, thus starting the field of seismology.

The great Voltaire[8] joined those who claimed it was an Act of God. The equally great Rousseau disagreed. Rousseau wrote to Voltaire" that it was hardly nature who assembled there twenty thousand houses with 6 or 7 stories. If the inhabitants of this large city had been more evenly dispersed and less densely housed, the losses would have been fewer or perhaps none at all."[9]

Natural disasters occur on built environments. Rousseau was prescient. Extreme natural hazards are only extreme when they involve great losses in lives or property.

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[4] USGS, Historic Earthquakes: New Madrid 1811-1812 Earthquakes, http://earthquake.usgs.gov/earthquakes/states/events/1811-1812.php.
[5] It is estimated to be a 8.5-9.1 on the MW scale (local magnitude scale) rather than the Richter Scale. Mark Molesky, This Gulf of Fire: The Destruction of Lisbon or Apocalypse in the Age of Science and Reason 6 (2015). The earthquake zone covered 5.8 million miles. Tremors were felt not only in Portugal, but also in Sweden, Norway, Germany, Netherlands, Ireland, Italy, Sardinia, Greenland, Cape Verde, the Azores, England and Venice. Id. at 111-115. It was especially damaging in Morocco and Tunisia in North Africa. Id. at 18-19. A tsunami hit Lisbon ½ hour after the earthquake. It also struck Spain, Morocco, Northeast Brazil, the West Indies, and Newfoundland. Waves reached Brittany, France, Brest, Cornwall, Plymouth, and Galway, Ireland. Id. at 143-4. See also, Edward Paice, Wrath of God: The Great Lisbon Earthquake of 1755 (2008) and Nicholas Shady, The Last Day: Wrath, Ruin & Reason in The Great Lisbon Earthquake of 1755 (2009).
[6] Marc-Andre Gutscher, What Caused the Great Lisbon Earthquake? Science, Aug. 27, 2004 at 1247. The earthquake damaged cities in Morocco with substantial loss of life in Algeria and Morocco and the tsunami reached Ireland, Cornwall in England and the Caribbean, 1755 The Great Lisbon Earthquake and Tsunami, Portugal, http://www.sms-tsunami-warning.com/pages/tsunami-portugal-1755.
[7] For a deconstruction of the Act of God defense in Tort Law, see Denis Binder, Act of God? Act of Man?: A Reappraisal of the Act of God Defense in Tort Law, 15 The Rev. of Litig. 1 (1996).
[8] Voltaire used the Great Lisbon Earthquake of 1755 for background in his famous book, Candide.
[9]Patrick Jacobe & Olivier Cadotte, Voltaire, Rousseau and the Lisbon Earthquake of 1755, https://prezi.com/w6kyixuyhllf/voltaire-rousseau-and-the-lisbon-earthquake-of-1755/.

The Great Lisbon Earthquake is an example of the global interconnectivity of nations when struck by the forces of nature. Natural forces do not respect artificial political boundaries.[10]

Large populations are concentrated in a relatively small land mass in Europe. Natural hazards are thereby likely to affect several nations. This table[11] of the populations, geographic sizes, and per capita densities of Northern Europe, Southern Europe, and Western Europe, compared to Saudi Arabia, show the great risk to Europe from natural disasters.

Area	Population	Square Miles (sm)	Per Capita Population
Northern Europe[12]	102,911,380	656,765	157/sm
Southern Europe[13]	152,163,420	500,005	304/sm
Western Europe[14]	191,303,129	418,959	458/sm
Saudi Arabia[15]	32,642,000	827,751	39/sm

We see in Northern, Southern, and Western Europe about three dozen countries, many small, on a relatively small land mass. Thus, a meteorological or geological hazard poses a great threat to a large number of countries.

By way of contrast, a similar threat in Russia, Canada, the United States, China, Brazil, Australia or India might be confined within the country's boundaries, although affecting many states or provinces within the country.

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[10] John Donne wrote in Devotions upon Emergent Occasions, Meditations XVII:
"No man is an island entire of itself; every man
is a piece of the continent, a part of the main;
If a clod be washed away by the sea, Europe
Is the less, as well as if a promontory were, as
well as any manner of thy friends or of thine
own were; any man's death diminishes me,
because I am involved in mankind.
And therefore never send to know for whom
the bell tolls; it tolls for thee."

[11] The figures for the table come from the Worldometer, which updates the population figures on a continuous basis. I am using their fixed numbers from July 1, 2016.

[12] http://www.worldometers.info/world-population/northern-europe-population/. The countries included in Northern Europe are Estonia, Denmark, Finland, Iceland, Ireland, Latvia, Lithuania, Norway, Sweden, and the United Kingdom as well as the Channel Islands, Faroe Islands, and the Isle of Man.

[13] http://www.worldometers.info/world-population/southern-europe-population/. Southern Europe includes Albania, Andorra, Bosnia & Herzegovina, Croatia, Greece, Italy, Macedonia, Malta, Montenegro, Portugal, Serbia, Slovenia, and Spain, as well as Gibraltar, the Holy See and San Marino.

[14] http://www.worldometers.info/world-population/western-europe-population/. Western Europe consists of Austria, Belgium, France, Germany, Liechtenstein, Luxembourg, Monaco, the Netherlands, and Switzerland.

[15] http://www.worldometers.info/world-population/saudi-arabia-population/.

The Great Storm of 1703

The Great Storm of 1703[16] struck England five decades earlier than the Great Lisbon Earthquake of 1755. The storm was especially disastrous in England as it struck populated cities and harbors of South England. It also cut a 300 mile (500 km) wide belt of destruction across southern England, Wales, the southern North Sea, the Netherlands, North Germany, Denmark, and parts of France, Sweden, the Baltic Sea, Finland, and Russia.[17] Substantial property damage occurred throughout the impacted area. The storm may, or may not, have originated in the Caribbean and skipped past the states of Florida and Virginia.[18]

The storm struck with hurricane force winds on December 7, 1703 as the culmination of two weeks of steadily increasing stormy conditions. An estimated 8,000-15,000 perished including 6,000 sailors.[19] Hundreds of ships were sunk or damaged, including 13 British Navy warships in the English Channel. Millions of trees were leveled.

Daniel DeFoe collected stories from the survivors and witnesses. He published "The Storm" in 1704, which is claimed to be the first exercise of modern journalism.

The Great Storm of 1703 may have been extreme, but it is not an anomaly. The North Sea area is subject to storms with strong winds comparable to tropical hurricanes combined with storm surges during high tides. These storms are often called cyclones. The North Sea is a shallow, semi-enclosed shape, which can produce strong storm surges.[20] A storm surge during a spring tide is highly risky, with low lying areas along the coastline especially vulnerable.[21] Professor Lamb identified roughly 150 severe storms in the North Sea between 1509 and 1989.[22]

Professor Lamb developed a scale to measure the severity of the storms, looking at the greatest surface wind speeds, the greatest area covered at any stage by wind causing substantial damage, and the total duration of the damaging winds during the life of different storms.[23]

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[16] This article does not attempt to consider the effects of climate change. We should note though that the Great Strom of 1703 occurred during The Little Ice Age, which indicates that these storms can occur in cooler times and as well as warming times.
[17] Herbert lamb and Knud Frydendahl, Historical Storms of the North Sea, British Isles and Northwest Europe 59 (Cambridge University Press 1991), hereinafter referred to as "Lamb.".
[18] Id. at 62.
[19] BBC, Earth – In 1703 Britain was struck by its worst ever storm, http://www.bbc.com/earth/story/20170309-in-1703-britain-was-struck-by-possibly-its-worst-ever-storm?ocid=ww.social.link.email.l
[20] . Alexander Hall, The North Sea Flood of 1953, Environment and Society Portal, Arcadia 2013, No. 5, http://www.environmentandsociety.org/arcadia/north-sea-flood-1953.
[21] L. Fenoglio-Marc, et al, "Cyclone Xaver seen by geodetic observations," Geophysical Research Letters, Oct. 2015 at 9925.
[22] Lamb, supra n. 18 at 37-193.
[23] Id. at 7.

The 1703 storm only came in fifth on his scale with a rating of 9,000. The leading storm was a 1986 cyclone rating a 20,000, but it was centered in the North Atlantic off Greenland and thus outside the central region of his study.[24] The other storms rated ahead of the 1703 storm were in 1792 and 1825, both rated at 12,000, and 1694 at 10,000. By way of comparison, the devastating storm of 1953 was only rated a 6,000.[25]

Both the Great Storm of 1703 and the Great Lisbon Earthquake of 1755 occurred during the Age of Enlightenment and helped foster the scientific study of natural hazards. No longer could the rubric "Act of God" explain all natural phenomena.

The Foreseeable Unforeseeability of Extreme Natural Forces

Extreme natural hazards are seemingly paradoxical because they can be both foreseeable and unforeseeable simultaneously. For example, hydrologists map floodplains. Geologists identify seismic zones. Meteorologists identify, predict and track storms. However, the identification of general risks is but a preliminary step in predicting or controlling the specific risk, which is often outside human capability.

The general recognition of a potential extreme hazard does not necessarily allow for specific predictions for the timing, severity, and locale of impact. For example, the timing of an earthquake, its location, duration, velocity, magnitude, point of impact, and direction are still unpredictable. Tornadoes can be tracked with warnings often available for residents to seek shelter, but the loci of a tornado touchdown is unpredictable. Similarly, a hurricane heading towards the Atlantic or Gulf coasts of the United States has a wide arc within which to strike land.

In addition, natural risks remain despite the greatest efforts of engineers. Try as they might, humans often cannot prevent, deter, or divert extreme forces of nature, such as earthquakes, hurricanes, tornadoes, and volcanoes Indeed, human activity can create or enhance natural hazards.

The reality is that every major disaster, even of seemingly natural origin, will probably involve human fault; a combination of poor decisions and acts of negligence will often coalesce to magnify the impact and damages. Negligence may exist in planning, designing, construction, operations, maintenance or inspection. Deferred maintenance may be a problem with aging facilities and systems.

The Human Factor

Floods are a prime example of people adding to nature's risk. Humans build in and inhabit natural flood plains. They often channel rivers and streams in straight lines, increasing the velocity, whereas natural rivers and streams are often serpentine in shape. The destruction of open space increases runoff. Humans replace permeable

[24] Id. at 8.
[25] Id.

soils with asphalt roads, concrete foundations and parking lots, structures, tiles, and roofs, increasing the runoff headed downstream. Developing the littoral zone removes coastal wetlands, nature's sponge, which serves as a buffer zone against storms..

Two commentators recognized:

Though triggered by natural events such as floods and earthquakes, disasters are increasingly man-made. Some disasters (flood, drought, famine) are caused more by environmental and resource mismanagement rather by too much or too little rainfall. The impact of other disasters, which are triggered by acts of nature (earthquake, volcano, hurricane) are magnified by unwise human actions.[26]

Upstream flood control measures, such as dikes and levees, may protect the upstream area, but increase the pressure on weaker dikes and levees downstream. The European Union recognizes therefore that flood basin management requires river basin management plans[27] and coordination between member states.[28]

Stripping forests remove watershed protection, and again sends more waters downstream. Conversely building in woody areas changes the calculus of wildfires.

Construction methods can increase or decrease the risks during hurricanes. Maintenance, or the lack thereof, affects the ability of structures to withstand forces of nature.

In addition, complacency sets in. Maintenance expenditures are often cut in the absence of problems. The 'squeaky wheel" often drives infrastructure spending as a political and practical matter.

Preventative Measures to Reduce Flooding Risks

Common measures implemented to reduce, if not eliminate, flooding include dams and reservoirs, dikes, levees, and flood gates. Dams, dikes, and levees can provide protection within their design limits if properly designed, constructed, and maintained. Large flood detention basins and polders[29] are also helpful. Yet, Munich Re, the large reinsurance company, cautions us that 100% protection is impossible, short of zero human habitation. Dikes and levees can break. Uncontrolled

[26] Anders Wijkman & Lloyd Timberlake, Natural Disasters: Acts of God or Acts of Man 6 (1984).
[27] Directive 2007/60/EC of the European Parliament and the Council of 23 October 2007 on the assessment and management of flood risks, http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32007L0060:EN:NOT.
[28] Id at 5
[29] Regionalism poses a problem though. Creating polders though has met with resistance in Germany by regional leaders who cannot justify their existence to reduce flooding in downstream areas. DW, Top Stories/Germany, German flood prevention still can't prevent floods, December 6, 2013, http://www.dw.com/en/german-flood-prevention-still-cant-prevent-floods/a-16876765.

construction in exposed areas, such as coastal areas and other low lying areas close to rivers and lakes, increases the risk.[30]

Structural solutions will often be unable to prevent or temper the extreme forces of nature. Structures have both design limits and design lives. For example, a facility designed for the 100 year event will be ineffective against the 200 or 500 year event. Structures wear out over time, quicker without proper maintenance.

Learning from Disasters

Smart societies and leaders learn from disasters. They try within the limits of technology to prevent or ameliorate the next one. For example, England realized after the disastrous flood of 1953 that it lacked a warning system to alert residents in advance and evacuate to safer grounds. Thus England established a storm tides warning system within the Met Office.[31]

Germany recognized after the 2002 flooding that its flood control measures were inadequate. It adopted an integrated flood risk management system pursuant to the German Flood Protection Act of 2005 and the European Floods Directive of 2007.

The German floods of 2013 were the most severe in 60 years, exceeding the 2002 storm. Losses were estimated at €6-8 billion compared to €11 billion in 2002.[32] The changes made included land use planning, preparedness measures, warning systems, coordinated disaster response, and targeted maintenance of flood-defense systems.[33]

The Netherlands built the Delta Works to reduce the risk to its low-lying lands. England created the Thames Barrier to protect London and surrounding areas from storm surges after the 1953 North Sea Flood. Both systems have been working to date.

We also have to recognize human fallibility in decision making. People can be remiss in their decisions. For example, emergency action plans may not be up to date or poorly implemented.

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[30] MunichRe, Flooding – There is no such thing as complete protection, May 7, 2013, https://www.munichre.com/topics-online/en/2013/07/flooding

[31] Met Office, 1953 east coast flood – 60 years on, http://www.metoffice.gov.uk/news/in-depth/1953-east-coast-flood.

[32] European Commission, Science for Environment Policy: Flood Risk Management Has Improved in Germany, # 469, Sept. 9, 2016, http://ec.europa.eu/environment/integretion/research/newsalert/pdf/flood_risk_management_improved_germany_469a2_en.pdf..

[33] Id., Annegret H. Thicken, et al, Review of the flood risk management system in Germany after the major flood in 2013, 21 Ecology and Society #2 at 51 (2016),http://dx.doi.org/10.5751?ES-08547-210251.

Earthquakes

The risks of earthquakes, volcanoes, and tsunamis are interrelated. Northern Europe is viewed as geologically stable with low seismic risks, but it is not though seismic free. One list of earthquakes in Northern Europe from 1375 to 1989 recognized over 5200 events, of which 28 were 5 and over on the Richter Scale and one measured 6.0.[34]

Britain experiences 200-300 earthquakes annually, but most are too small to notice.[35] However, a major exception was a 6.1 earthquake on June 3, 1931. The epicenter was 60 miles offshore at Dogger Bank in the North Sea. Extensive damage was reported in Britain[36]. Two other major North Sea centered quakes were the 1904 Oslofjord and a 1927 earthquake off Norway.[37] This study found 6 earthquakes of 6 or above and 28 of 5 or above between 1759 and 1977.[38]

More recently a 3.8 quake 93 miles out in the North Sea was felt along the Yorkshire coast.[39] A 5.2 earthquake was felt in Lincolnshire in 2008.[40]

Roermond in the Netherlands experienced a 5.3 earthquake on April 13, 1992. Researchers discovered that the Roer Valley of Belgium, Germany, and the Netherlands sits between two fault systems.[41]

The major seismic risks in Europe are centered in the Mediterranean and Iceland. Countries at risk include Bulgaria, Greece, Italy, Romania, Turkey, Recent decades have witnessed major earthquakes in Izmir, Turkey[42] and L'Aquila, Italy.

The Italian L'Aquila earthquake aftermath raised tremors throughout the scientific community. A series of minor earthquakes preceded a large earthquake, which killed 309 and left over 1,000 homeless. A public conference a week before the large quake issued assurances of safety. Six scientists and a public official were convicted in

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[34] T. Ahjosa & M.Uski, Earthquakes in northern Europe 1375-1389, 207 Tectonophysics 1, 14 Table 2 (992).

[35] BBC News, Science & Environment, Q&A: UK's small-scale earthquakes, http://www.bbc.com/news/science-environment-12112307.

[36] The earthquake was felt in Great Britain, Belgium, the Netherlands, Northern France, Germany, Norway, and Denmark. Frode Ringdal, Seismicity of the North Sea Area, in A. R. Ritsema & A. Gurpunar, Seismicity and Seismic Risk in the offshore North Sea Area (1982.

[37] The Oslofjord earthquake severely damaged a few buildings, but resulted in no fatalities. Id. at 68. The epicenter of the 1927 quake was off the west coast of Norway. The quake was felt over Scotland, East England, the Shetland Islands, and Norway south of Trondheim. Id. at 69. A list of North Sea earthquakes is available at earthquake track, http://earthquaketrack.com/r/north-sea/recent.

[38] Id. at 67, Table 2.

[39] Paul Johnson, How a North Sea earthquake caused mayhem on the east coast of Britain, Hull Daily News, January 4, 2017, http://www.hulldailymail.co.uk/how-a-north-sea-earthquake-caused-mayhem-on-east-coast-of-britain/story-30029534-detail/story.html.

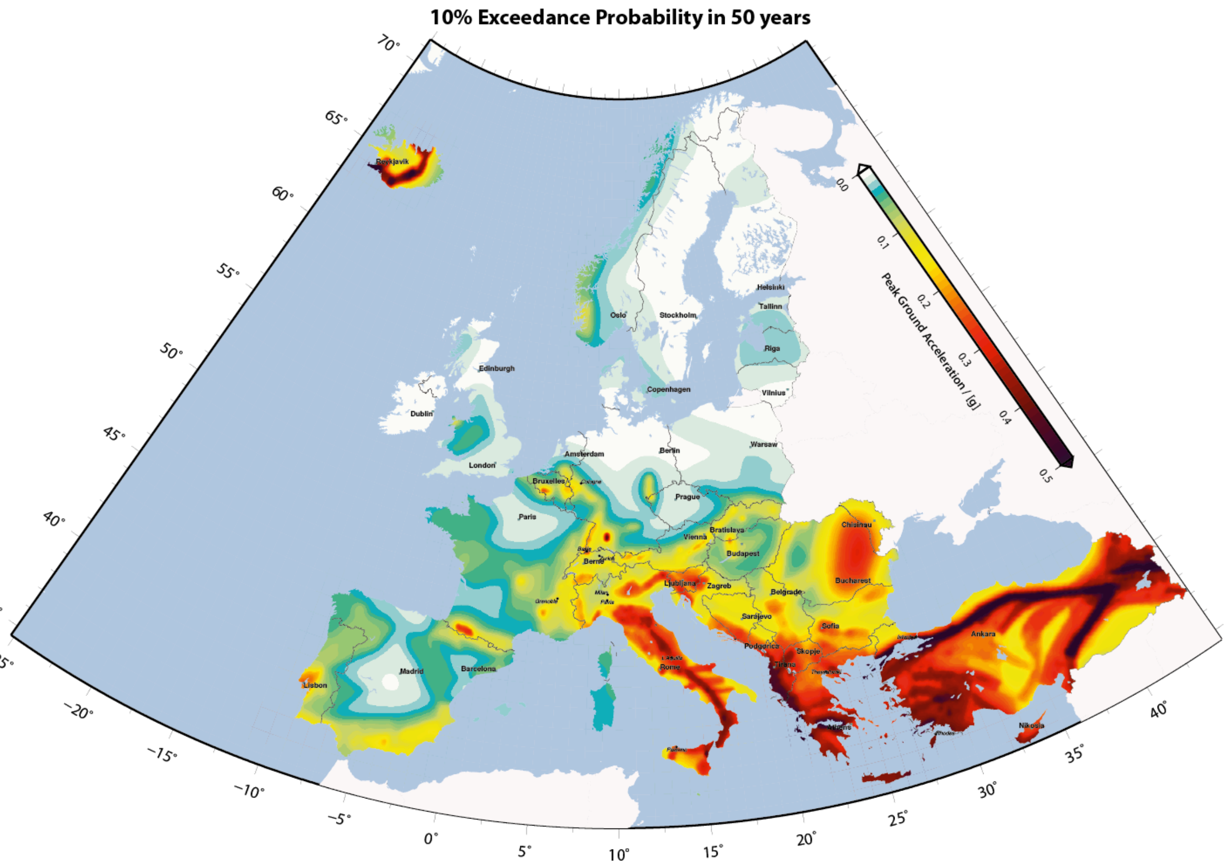
[40] Id.

[41] T. Camelbeeck & M. Meghraoui, Large earthquakes in Northern Europe more likely than once thought, 42 EOS Transactions American Geophysical Union 405 (October 15, 1966), https://www.researchgate.net/publication/248817999_Large_earthquakes_in_Northern_Europe_more_likely_than_once_thought

[42] The 7.6 1999 Ismit Earthquake killed over 17,000 can caused substantial property damage.

October 2013 of miscommunications of safety for issuing false assurances of safety The convictions of the scientists were overturned the next year, and later for the public official who said "there was no danger."

2013 European Seismic Hazards map (ESHM-13)



Volcanos

Volcanic eruptions are known risk in Iceland and southern Europe, especially around the Mediterranean. Mount Etna and Mount Vesuvius have become the lore of history.

Iceland experiences frequent volcanic eruptions. 39 eruptions were recorded in the 20th and 21st centuries.[43] The plume of ash from Iceland's Eyjafjallajukull volcanic eruption during April and May 2010 seriously interfered with air traffic for days.[44]

[43] Eruptions in Iceland: 20th and 21st Century Eruptions in Iceland, https://www.extremeiceland.is/en/information/about-iceland/eruptions-in-iceland-since-1900.
[44] For example, the UK closed its airspace from April 15-20, 2010 because of the Eyjafjallajokull eruption. Microscopic particles of volcanic ash can be extremely dangerous to airplane engines. Eyjafgallajukull Eruption, Iceland/ April-May 2010, http://www.bgs.ac.uk/research/volcanoes/iceland_ash.htm.

Tsunamis

Tsunamis are not a common hazard for Northern Europe, but the Great Lisbon Earthquake of 1755 showed that a major earthquake off Portugal could send waves around the Atlantic Ocean and Mediterranean Sea. The tsunami risk is greater in the Mediterranean and Black Sea. Several European countries participate in the 39 country Intergovernmental Coordinating Group for Tsunami Early Warning and Mitigation System in the Northeastern Atlantic, the Mediterranean and Connected Seas.[45]

A total of 290 tsunamis have been recorded in the Norwegian Sea, North Sea, Northeastern Atlantic, Black Sea, and the Mediterranean.[46] 10% of the world's tsunamis have occurred in the Mediterranean.[47] The Mediterranean's tsunamis often do not provide a long warning time because of its semi-enclosed basin and short travel times of the waves before they strike shore.[48]

Flooding

Erika Boustad in Scientific American posited extreme floods may be the new norm.[49] History tells us that severe flooding, often in coastal areas, has been the greatest natural threat to Europe, which now seems to be experiencing severe flooding annually.[50]

The cliché is that "You can't control nature." The major risk that has seemingly been a constant through the centuries is flooding, both from coastal storms and excessive precipitation inland. Some of the coastal storms have winds strong enough to constitute a "cyclone." Heavy precipitation can also come from the Mediterranean.

A look at some of the 20th and 21st Century floods will illustrate the existential threat to Northern Europe from floods from costal storms, and reaffirm the thesis that the storms do not respect political boundaries.[51]

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[45] The ICG/NEAMTWS was established by the Inter-governmental Oceanographic Commission of UNESCO in June 2005. Resolution XXIII.14
[46] Id. at 24.
[47] Intergovernmental Oceanography Commission, 10 Years of the North-eastern Atlantic, the Mediterranean and Connected Seas Tsunami Warning and Mitigation System: Accomplishments and Challenges for the Next Tsunami, IOC/INF -1340 at 22 (Feb. 2017).
[48] Id. at 8.
[49] Erika Boustad, Natural Disasters: Extreme Floods May be the New Norm, Scientific American, https://www.scientificamerican.com/article/extreme-floods-may-be-the-new-normal/.
[50] See e.g. German Committee for Disaster reduction (DKW), Severe Storms over Europe: A Cross-Border Perspective of Disaster Reduction. Second International Workshop, March 26-26, 2007.
[51] I hate to cite Wikipedia, but it provides a list of notable recorded floods in Europe, https://en.wikipedia.org/wiki/List_of_floods_in_Europe.

1953

The North Sea Flood of January 31-February 1, 1953 was especially devastating Europe recovering from World War II.[52] High spring tides coupled with a deep Atlantic depression and strong northerly gales led to storm surges. The lack of warning systems added to the casualty list in England with 307 deaths and 19 in Scotland as well as 230 at sea. Over 1,600 km of coastlines were damaged and sea walls were breached in England. Dikes failed in the Netherlands. Water levels rose up to 18.4' above mean sea level.[53]

32,000 were evacuated in England and 160,000 acres inundated with sea water. Wind gusts reached 127mph at Costa Hill, Orkney.[54] Winds were recorded at up to 120mph in England and Wales. 24,000 properties were damaged.[55]

The Netherlands was struck harder. 1,836 deaths occurred in the storm. 340,000 acres were flooded, 100,000 evacuated, and 47,300 buildings damaged.[56]

The Great Storm of 1987

The November 15-16, 1987 storm was considered the worst since 1703 as it struck Northern France and Southern England especially hard. The storm cut a swath of damage from Norway to Portugal and Spain. Cyclone force winds reached 135mph at Pointe Do Roc, Brittany, France. One gust at Gorleston, Norfolk, England was recorded at 122mph. The wind speeds between North London and Great Yarmouth had a return period of 200 years.[57]

England incurred £1.5 billion in damages with18 lives lost and 18 million trees leveled.[58] France lost 10 million trees. Norway experienced 4" of rain in 48 hours with flooding in Oslo.

2002

Record precipitation in Germany in August 2002 caused over €11 billion in damages.[59] The storm's impact revealed weaknesses in Germany's flood

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[52] For example, the sea defenses were in a dilapidated condition after the war. Alexander Hall, The North Sea Flood of 1953, Environment and Society Portal, Arcadia 2013, No. 5, http://www.environmentandsociety.org/arcadia/north-sea-flood-1953.

[53] The North Sea Storm of 2013, Arcadia 2013, No. 3, http://www.environmental society.org/arcadia/nortg-sea-flood-1953

[54] Met Office, 1953 East Coast Flood – 60 Years On, http://www.metoffice.gov.uk/news/in-depth/1953-east-coast-flood.

[55] Environmental & Societal Portal, The North Sea Flood of 1953, http://www.environmentandsociet.org/arcadia/north-sea-flood-1953.

[56] Id.

[57] Risk Management Systems, RMS Special Report, The Great Storm of 1987: 20-Year Retrospective (2007), http://forms2.rms.com/rs/729-DJX-565/images/ws_1987_great_storm_20_retrospective.pdf.

[58] Daily Mail, The Great Storm of 1987: How the 'hurricane' claimed 18 lives, flattened 15million trees and caused damage costing £1.5billion, http://www.dailymail.co.uk/news/article-2478167/Great-Storm-1987-claimed-18-lives-flattened-15m-trees-caused-1-5bn-damage.html.

management, including a poor warning system, poor structural maintenance, a lack of risk awareness, and failure to understand response efforts.[60]

Cyclone Xynthia 2010

Cyclone Xynthia was a massive windstorm which struck western Europe between February 27 and March 1, 2010. The death toll was 47 with damages about €2.5 billion. It caused damage in Portugal, Spain, Germany, and England, but hit the France coast especially hard. 29 died in La Faute-sur-mer in homes built since 1980 in a "red zone" meant to bar development. 22 of the victims were over 60, while hundreds of homes were flooded.[61] The mayor was sentenced to 4 years; the officer in charge of building permits received 2 years while her son in charge of ensuring and monitoring the safety of the seawall was sentenced to 18 months.[62] They had permitted development in the Red Zone while failing to ensure the safety of the coastal zone. The storm was a natural force, but building homes in the restricted area "protected" by poorly located, fragile sea walls was the human cause that magnified damages.

2013

Widespread flooding occurred in Central Europe in June 2013. Germany. Austria, the Czech Republic, Slovakia, Hungary, Croatia, Serbia, and Poland were hit hard.[63] The Danube River in Budapest hit an historic high of 29'. Flood waters rose to 24' in Magdeburg, Saxony-Anhalt. Parts of Warsaw flooded.[64] The Danube River is joined up by two tributaries, the Inn and the IIz in Passau, Germany. Passau recorded its highest flood level since 1501.[65]

Cyclone Xaver: The North Sea Flood of 2013

Cyclone Xaver struck Northern Europe on December 4-10. 2013,[66] hitting Belgium, Denmark, the Faroe Islands, Germany, Ireland, Lithuania, the Isle of Man, Netherlands, Norway, Poland, Scotland, Sweden, and the United Kingdom. The storm was characterized by hurricane force gusts, torrential rains, and storm surges.

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[59] Science for Environmental Policy, Flood risk management has improved in Germany #469 (September 9, 2016).
[60] Annegret H. Thicken, et al, Review of the flood risk management system in Germany after the major flood in 2013, 21 Ecology and Society #2 at 51 (2016),http://dx.doi.org/10.5751?ES-08547-210251.
[61] Eliasbetta Genovese, et al, Disaster Risk Management and Territorial Governance: Lessons from Xynthia Storm in France 3 (FIG Working Week 2012).
[62] Visiting France, French mayor jailed for four years over 2010 storm deaths, http://en.rfi.fr/visiting-france/20141212-france-mayor-jailed-four-years-xynthia-storm.
[63] Annegret H. Thicken, et al, Review of the flood risk management system in Germany after the major flood in 2013, 21 Ecology and Society #2 at 51 (2016),http://dx.doi.org/10.5751?ES-08547-210251.
[64] BBC, Thousands flee flood-hit parts of Germany and Hungary, June 10, 2013, http://www.bbc.com/news/world-europe-22835154.
[65] Jim Andrews, Historic Flooding in Central Europe, AccuWeather (June 9, 2013), http://www.accuweather.com/en/weather-news/historic-flooding-in-central-e/13854991.
[66] It was named "Bodic" in Denmark, Ksawery in Poland, and "Swen" in Sweden.

Some storm surges exceeded those of 1953. Sea levels rose 19" in Hull and 15" in Dover.[67] Wind gusts reached 142mph in Scotland and up to 98mph on the Germany-Denmark border. 1,400 homes were flooded in England and Wales. 100,000 homes in Scotland and over 6,500 in Northern Ireland lost power.

Rail service was cancelled in all of Scotland and shut down in 1/3 of Germany. Waves up to six meters high struck Hamburg, the second highest surge since 1825.[68] Two towns in Denmark, Frederikssund and Frederiksvaerk, were evacuated.

The Thames Barriers were closed for two days, preventing the flooding of London. The Netherlands was also protected by the Eastern Scheldt barrier created since 1953.[69]

2014

The Balkans in 2014 were struck by their worst flooding in 120 years.[70]

2016

A series of severe convective storms struck Europe in May and June 2016. Fatalities occurred in Belgium, France, Germany, and Romania.[71] Germany experienced severe thunder storms for 15 days from May 26-June 9. Flash floods, hail, and tornadoes accompanied the severe thunderstorms.[72] Rainfall at one point in Gundelsheim, Germany was 122mm (4.8') within 24 hours.[73]

Northeast France experienced up to six full weeks of rain within 24 hours.[74] The Seine River in Paris reached its highest levels since 1982. The 1982 flood level reached 20', which was lower than the record 26.2 inches in 1910.[75] The Louvre and

[67] A Level Geography, East Coast Flooding in UK – 5th December 2013, http://www.alevelgeography.com/coastal-flooding.
[68] Alert Worldwide, December 12, 2013, Extratropical Cyclone Xaver, http://alert.air-worldwide.com/EventSummary.aspx?e=726&tp=72&c=1, and http://alert.air-worldwide.com/EventSummary.aspx?e=65&c=1.
[69] Id.
[70] Alan Taylor, Balkans Struck by Worst Flooding in 120 Years, May 20, 2014, https://www.theatlantic.com/photo/2014/05/balkans-struck-by-worst-flooding-in-120-years/100739/.
[71] https://wwa.climatecentral.org/analyses/european-rainstorms-may-2016/
[72] David piper, et al, Exceptional sequence of severe thunderstorms and related flash floods in May and June 2016 in Germany, part I: Metrological background, 16 Natural Hazards and Earth System Sciences 2835 – 2850 (2016), http://www.nat-hazards-earth-syst-sci.net/16/2835/2016/nhess-16-2835-2016-discussion.html.
[73] Id.
[74] Tom Moore, Here's What Caused the Deadly Floods in Germany and France, The Weather Channel (June 1, 2016), https://weather.com/news/international/news/europe-flood-excessive-rain-blocking-pattern-germany-france.
[75] Lisa Blaise & Benoit Morenne, In Paris, the Seine Rises to Highest Level Since 1982, N. Y. Times, June 3, 2016, https://www.nytimes.com/2016/06/04/world/europe/paris-flooding-seine-louvre.html?_R=1.

Musee d'Orsay were closed to move works of art to safety.[76] Over 20,000 were evacuated in France and around 19,000 homes lost power.[77]

2017

Denmark, Germany, and Poland were hit hard by a storm in January 4,2017 with severe flooding. Sea levels reached 1.75 meters above normal. The Danish Meteorology Institute reported that the flooding was a 100 year flood in Wismar, Germany. Parts of Germany experienced the strongest storm surge since 2006.[78]

The Czech Republic, and Hungary experienced major flooding later in January along the Danube. Flooding hit an historic high in Budapest peaking at 8.49 meters, but the protective structures held.[79]

Conclusion

Let us recognize that extreme forces of nature are the norm - not a new normal. Extreme hazards defy human control. "Extreme hazards" by itself is a misnomer. Nature is nature. We are learning at great cost in lives, property, and dollars the limits of our ability to control geological and meteorological risks. Humans often cannot prevent or deter the extreme, unavoidable forces of nature, such as earthquakes, hurricanes, tornadoes, tsunamis, volcanoes, ice storms, and wildfires as well as more common risks such as flooding.

Flooding is consistently the greatest natural hazard in Europe. The flooding is usually directly, or indirectly, from coastal storms, often containing hurricane force winds. Even inland flooding will often be caused by coastal storms which passed over the coastal zone and moved inland.

Forces of nature though do not observe artificial political boundaries. Thus a tsunami unleased by an earthquake striking Lisbon can flow across the Atlantic to the Americas and then bounce back to Northern Europe. A North Sea storm can move on from the coast into Central Europe.

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[76] Aurelien Breeden, From Paris to Bavaria: Heavy Rains Cause Deadly Floods, New York Times, June 2, 2016. https://www.nytimes.com/2016/06/03/world/europe/france-germany-floods-rain.html?_r=0.

[77] Angelique Chrisafis, Paris Floods: There's something terrifying about it, The Guardian, June 4, 2016, https://www.theguardian.com/world/2016/jun/03/paris-river-seine-floods.

[78] Richard Davies, Denmark, Germany and Poland – Storm Surge causes Coastal Flooding, http://floodlist.com/europe/denmark-germany-poland-storm-surge-flood-january-2017.

[79] Daily Mail, Flooding of Europe Continues, http://www.dailymail.co.uk/news/article-134033/Flooding-Europe-continues.html

Simulation and Forecasting of Soil Moisture Content Variability Over Ogbomoso Agricultural Watershed Using the SWAT Model

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Abstract
Soil moisture has been recognised as an essential climate and hydrological variable that controls land surface processes. In this study, the soil moisture content within the Ogbomoso watershed, Nigeria was simulated for a 34-year period using the hydrological model, Soil Water Assessment Tool (SWAT). The model was also used to predict soil moisture for a period of 20 years. The SWAT model was calibrated and validated using observed soil moisture. The calibrated SWAT model performed well for the simulation of daily soil moisture. Statistical model performance measures, coefficient of determination (R^2) of 0.91, Nash-Sutcliffe efficiency (E_{NS}) of 0.64 and percentage difference of (D) of 13% for calibration and 0.88, 0.84 and 8% respectively for validation indicating good performance of the model simulations. The soil moisture simulated by SWAT showed a generally decreasing trend from 1984 to 2017. The 20 year predicted soil moisture by SWAT also showed a slightly decreasing trend from 2018 to 2037 which may have negative implications for crop yield. The variability in both the simulated and predicted soil moistures generally respond to precipitation decreasing and temperature rising in the region. The results suggest that SWAT model can reasonably simulate and forecast the spatiotemporal variation of the soil moisture in the area. Therefore, the SWAT model may become a good tool to study the regional hydrological variations. The result of this study could provide essential resource information for watershed managers and aid effective decision making by water resource manager in the area.

Keywords: Soil moisture, SWAT model, Watershed, simulations, forecasting

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Introduction

Soil moisture, which is the water stored in the upper soil layer, is a crucial parameter for a large number of applications, including numerical weather prediction, flood forecasting, agricultural drought assessment and water resources management. It has significant impact on climate change and climate system by mass and energy transfer (Ma, *et al.,* 2001). The soil moisture governs the process of evapotranspiration and the water transfer from the soil to the atmosphere. Though only a small percentage of total precipitation is stored in the soil after accounting for evapotranspiration, surface runoff and deep percolation, soil moisture reserve is critical for sustaining agricultural operations, crop monitoring and yield forecasting. Therefore, understanding the variability of soil moisture can help to understand the climate system, improve skills of simulation and forecast the change of climate.

Despite the importance of soil moisture to agricultural operation, crop monitoring and yield forecasting, soil moisture information is not widely available on a regional scale. This is highly because soil moisture is highly variable both spatially and temporally and is therefore difficult to measure on a large scale. The difficulty of observing soil moisture routinely over large area and its importance to many areas of the environment means that it is a property that needs to be simulated well. Only limited data sets of soil moisture exist in Nigeria because it is a difficult property to measure. Soil moisture is naturally heterogeneous because of difference in moisture-holding capacities of the soil at a very small scale and topography. The spatial and temporal variability of soil moisture is due to its heterogeneity in the soil property, land cover, topography and non-uniform distribution of precipitation and evapotranspiration.

The soil moisture is usually measured by agro-meteorological experimental stations which are very scares in Nigeria. This data are measured mainly for the agriculture, which are not adequate to evaluate the interaction between the land and the atmosphere. Usually, the positions of these stations do not take into consideration the diverse soil types, soil properties, land cover and land use, topography etc. on the soil moisture. Therefore, instead of using limited observations, the numerical model play a more important role in the research on the variability of soil moisture and hydrological processes. There are several models available today which are capable of simulating the watershed scale hydrologic processes. Each model has associated proficiency and limitations, and often the need of the study dictate which model is applicable. For this study, the Soil Water Assessment Tool (SWAT) model (Arnold *et al.,* 1998) was chosen due to its ability to simulate hydrologic processes and the fact that it considers the effects of topography, land use types, land cover, soil properties, vegetation properties on soil hydrological processes with the help of high resolution Digital Elevation model (DEM). The SWAT has gained international acceptance as a robust interdisciplinary watershed modelling tool able to adeptly predict hydrology (Gassman *et al.,* 2007). The SWAT has been used for wide range of environmental conditions, watershed scales and scenario analysis as described by Gassman, 2007.

The main objective of this study is to simulate and forecast soil moisture variability over Ogbomoso agricultural watershed. The specific objectives of this study are to (a) simulate the soil moisture content variability (b) forecast soil moisture variability (c) evaluate the implications of the simulated/forecasted soil moisture.

Materials and Methods

Study Site

Ogbomoso agricultural watershed is geographically located within 4^o 10'E to 4^o 20' E longitude and 8^o 00'N to 8^o 15'N latitude. The studied area lies within the crystalline Basement Complex of Nigeria (MacDonald *et al.,* 2000). The rock groups in the area include quartzites and gneisses (Ajibade *et al.,* 1988). The Ogbomoso watershed was selected to simulate hydrology under diverse vegetation, topography, soil and climatic conditions. It covers the total drainage area of 8.58 km^2. Ogbomoso metropolis has the Tropical wet and dry climate as it falls in the transition zone between the rain forest and the savannah. The region experiences a fairly high uniform temperature, moderate to heavy seasonal rainfall. The mean annual temperature is about 26.20 ^{o}C and the mean annual rainfall of 1200 mm. The regions around and within the Ogbomoso agricultural watershed has four seasons like most of the other area in the southern Nigeria. The long wet season starts from April to July; it is the season of heavy rainfall and high humidity. The short dry season is normally in August. This is followed by short wet season and last September to October. The last season is that of harmattan experienced at the end of November to mid March. The relative humidity is within the range 75–95%.

Ogbomoso lies in the transition zone forest of Ibadan geographical region and the northern savannah region. As a result of this, it is regarded to be of derived savannah vegetation. The town is seen to be a low land forest area with agricultural activities being the major activities carried out on it. Figure 1 shows the geographical location of the study area.

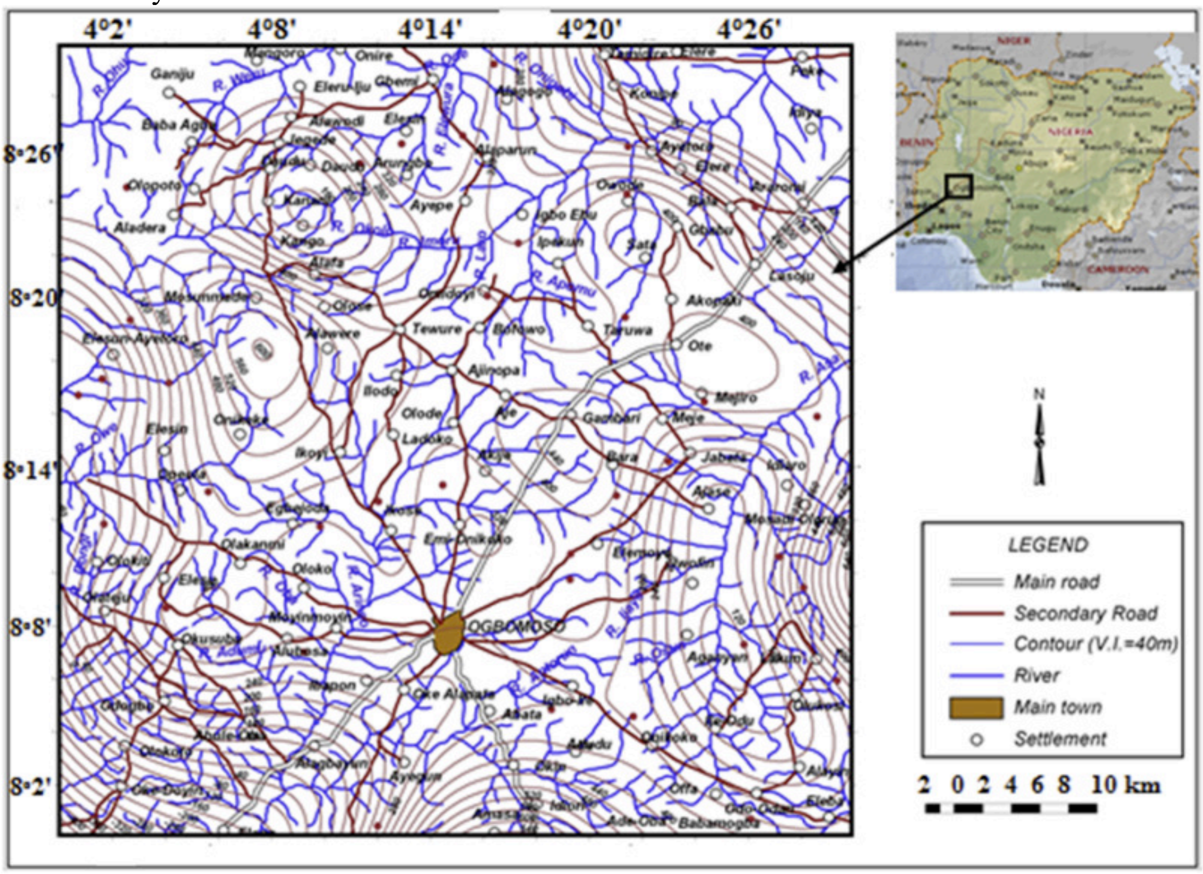

Figure 1: The map showing the area around the agricultural watershed

The SWAT Model Description

SWAT was developed in the 1990s by the United State Department of Agriculture (USDA) and is based on several Agricultural Resource Service (ARS) models that were already available (Neitsch *et al.,* 2005; Gassman *et al.,* 2007). The SWAT has been used to simulate watersheds around the globe, most often being chosen due to its robust capability to quantify the effects of land management practices on hydrological processes, water quality, and crop growth (Arnold *et al.,* 1998). Since its inception the SWAT model has continued to be improved and updated in accordance with advances in knowledge and remains actively supported by the USDA ARS (Neitsch *et al.,* 2005). There are several versions of the software freely available to the public; QSWAT, a version of the SWAT2012 model, interfaced with QGIS 1.4 was used in this study. The hydrologic component of the model calculates a soil water balance at each time step based on daily amounts of precipitation, runoff, evapotranspiration, percolation, and base flow. The water balance equation is presented in Eqn. (1) (Arnold *et al.,* 1998: Neitsch *et al.,* 2005)

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad (1)$$

where SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day i (mm H_2O), t is time (days), R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), E_a is the amount of evapotranspiration on day i (mm H_2O), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O), and Q_{gw} is the amount of return flow on day i (mm H_2O).

The SWAT model divides a watershed into sub-basins, connected by a stream network. Each sub-basin is composed of hydrologic response units (HRUs) which are unique areas within the sub-basin that account for differences in soils, land use, crops, topography, weather, and slope. The HRU delineation can minimize a simulation's computational costs by lumping similar soil and land use areas into a single unit (Neitsch *et al.,* 2005). Simulations are performed at the HRU level and summarized in each sub-basin. The simulated variables (water, sediment, nutrients, and other pollutants) are first simulated at the HRU level and then routed through the stream network to the watershed outlet (Arnold *et al.,* 1998; Neitsch *et al.,* 2005).

SWAT Input

As a physically based hydrological model, SWAT requires multiple sets of GIS data to create data layers to input in the model which control the hydrologic processes in the watershed. Key input datasets include topography, soils data, land use/land cover data, climate data, and management data.

Spatial input dataset were obtained from various free internet websites. The elevation data are the digital elevation model obtained at 30 m resolution from Shuttle Radar Topography Mission (SRTM) 1-arc second global elevation data. The land use map was from the MODIS (MODerate resolution Imaging Spectroradiometer) for a 10 year regrided global land cover dataset (2001-2010). The soil input was obtained from the digital global soil map of the FAO with a spatial resolution of 1: 5,000,000 m. All these data were in a raster format and geo-processed before for model input.

The climatic data inputs required by SWAT are precipitation, maximum and minimum temperature, solar radiation, relative humidity, and wind speed. Daily precipitation, daily maximum temperature and minimum temperature data, solar radiation, relative humidity, and wind speed were obtained from the Nigerian Meteorological Agency (NIMET) – (1979-2017) totalling a period of 39 years. The climate data input for the study area were all obtained from a single weather station available within the watershed.

The climate projection data which include the daily precipitation, and maximum and minimum temperatures at a spatial resolution of 0.22 x 0.22 lat/lon were obtained from the Canadian Regional Climate model and projected under the RCP4.5 scenario. This forecast data were bias corrected before use for SWAT model prediction. The summary of the SWAT input is shown in Table 1.

Table 1: Input database and sources for the SWAT model

Data Type	**Source**
Digital Elevation Model	SRTM 1-Arc-Second Global v3 (30 m)
Land-Use Data	MODIS (15-arc)(Broxton et al., 2014)
Soil Data	Digital global soil map FAOv3.6
Meteorological data	Nigerian Meteorological Agency (1984-2017)
Climate Projection Data	Canadian Regional Climate Model (2018-2037)

Model Set-up

Watershed delineation

The first step in creating SWAT model input is delineation of the watershed from a DEM. Inputs entered into the SWAT model were organized to have spatial characteristics. Before going in hand with spatial input data i.e. the soil map, LULC map and the DEM were projected into the same projection called UTM Zone 31N, which is a projection parameters for Nigeria. A watershed was partitioned into a number of sub-basins for modelling purposes. The watershed delineation process include five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub-basin parameters. For the stream definition, the threshold based stream definition option was used to define the minimum size of the sub-basins.

Hydrological Response Units (HRUs)

The land area in a sub-basin was divided into HRUs. The HRU analysis tool in QSWAT helped to load land use, soil layers and slope map to the project. The delineated watershed by QSWAT and the prepared land use and soil layers were overlapped 100%. HRU analysis in SWAT includes divisions of HRUs by slope classes in addition to land use and soils. The multiple slope option (an option which considers di□erent slope classes for HRU definition) was selected. The LULC, soil and slope map was reclassified in order to correspond with the parameters in the SWAT database. After reclassifying the land use, soil and slope in SWAT database, all these physical properties were made to be overlaid for HRU definition. For this specific study a 20% threshold value for land use, 10% for soil and 5% for slope were used. The HRU distribution in this study was determined by assigning multiple HRU to each sub-basin.

Model Calibration, Validation and Evaluation

Stream flow is often the only component of the water balance that is regionally observed, and hence, widely used for calibrating hydrological model. However, stream flow data in the study area in not available besides, stream flow account for a smaller fraction of the hydrological component than evapotranspiration and soil moisture. In this current study, soil moisture is the hydrological component of interest and it would be ideal to use soil moisture for calibration if the measured data were available at the study area in a natural hydrological setting (without irritation). Since the study area is a natural hydrological setting, five years daily satelite-based soil moisture data (2006-2010) from ESA CCI soil moisture project for the region under investigation was used for the SWAT model calibration. The calibration procedure made by SWAT developers (Santhi *et al.,* 2001; Neitsch *et al.,* 2007) was carefully followed.

Due to lack of long term *in situ* measurement of soil moisture at the study area, both the short term *in situ* measurement of daily soil moisture taken at the study area (April – July, 2017) and five years daily soil moisture data from ESA CCI (2011-2015) were used to validate the SWAT model.

Model performance were evaluated using three statistical model performance measures. The three statistical model performance measures are the percentage difference (D), the regression coefficient (R^2) and the Nash and the Sutcliffe efficiency (E_{NS}). SWAT developers assumed an acceptable calibration and validation for hydrology for percentage difference (D), the regression coefficient (R^2) and the Nash & Sutcliffe efficiency (E_{NS}) at $D \leq 15\%$, $R^2 > 0.6$, and $E_{NS} > 0.5$ respectively (Santhi *et al.,* 2001; Moriasi *et al.,* 2007).

Soil Moisture Measurement

The SM150T soil moisture sensor manufactured by delta-T Devices Ltd, Cambridge, UK was employed to measure soil moisture and soil temperature in this study. The use of this equipment was based on its highly dependable sensor with exceptional salinity and temperature stability for continuous measurements. The SM150T is built to withstand long term burial as the sensor, connectors and cable are all environmentally protected. The moisture accuracy of SM150T is 3% (after soil specific calibration) and the built-in temperature sensor achieves 0.5 °C accuracy.

The SM 150T soil moisture sensor kit comes with SM 150T sensor with two sharp pins, a GP1 data logger and a HH2 Moisture Meter used to establish connectivity to a computer for data download. The SM 150T was pushed into the soil until the rods were fully inserted to ensure good contact with the soil for continuous logging - to provide moisture and temperature data. Soil moisture and soil temperature in the study area were recorded at a range of logged interval of 30 minutes at the depth the soil moisture probe has been installed (~ 5cm). The equipment was calibrated according to the general calibration procedure for mineral and organic soil provided by the manufacturer. Figure 2 shows the set-up for the measurement of soil moisture and soil temperature in the study area.

Figure 2: Set-up for the measurement of soil moisture and soil temperature.

Result and Discussion

Watershed Delineation and Hydrological Response Unit

QSWAT2012 applies the TAUDEM V5 (Terrain Analysis Using Digital Elevation Model version 5) to delineate streams within watersheds. A total of 43 sub-basins were delineated and 94 HRUs formed within the Ogbomoso agricultural watershed based on land-use/soil/slope thresholds of 20/10/5 (%) respectively (see Figure 3). An intermediate slope definition of 10% was initially used to differentiate HRUs into those with an average slope between 0-10 % and those from 10 % to the 35 upper limit of 9999.

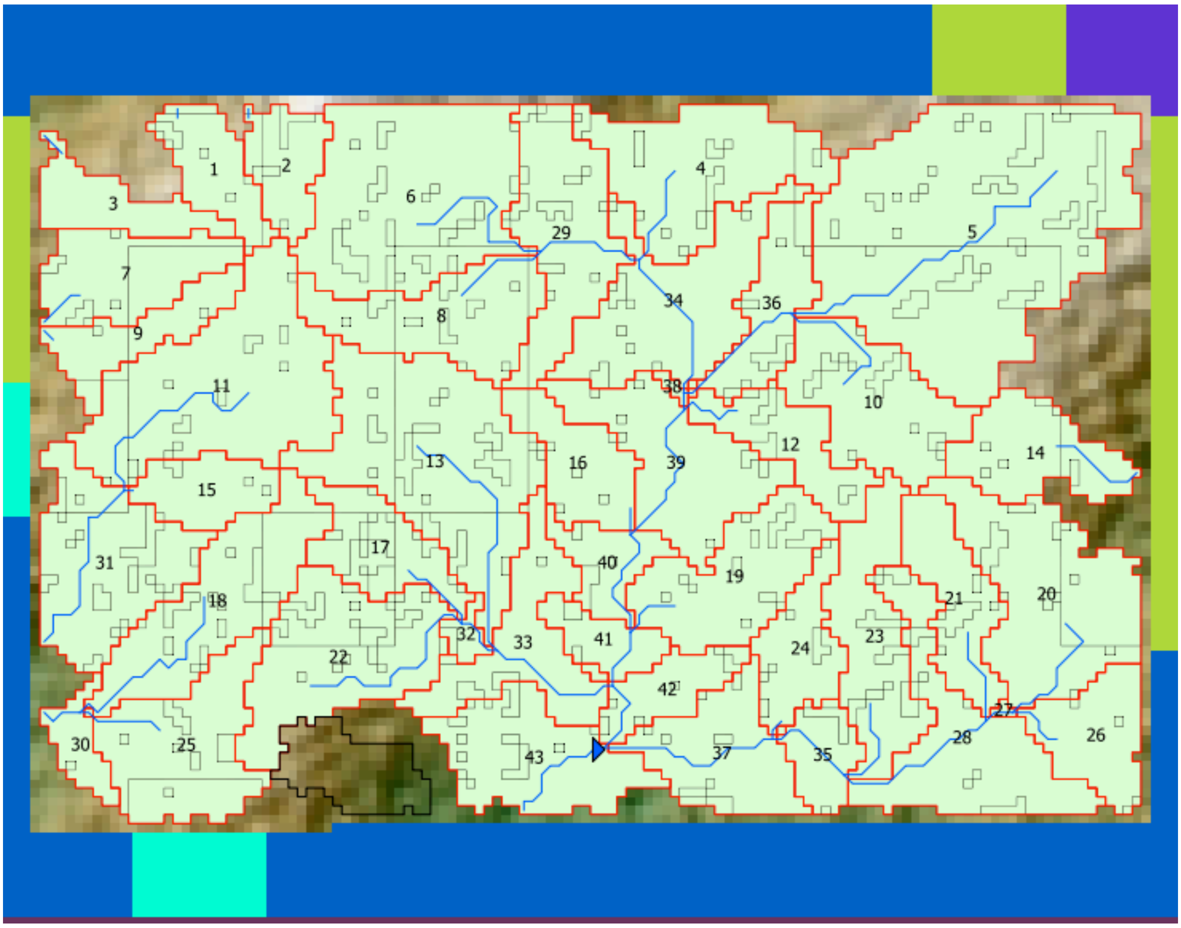

Figure 3: Full HRUs formed from land use/soil/slope characteristics for 20/10/5 (%)

Landuse and Soil Categories

Four dominant land use categories and one soil type were observed within Ogbomoso watershed as shown in Table 2. The soil type is known as Alfisols. They are arable soils with water content adequate for at least three consecutive months of the growing season. Prior to cultivation they are covered with natural broad-leaved deciduous forest vegetation, sometimes interspersed with needle-leaved evergreen forest or with grass. Occupying just under 10% of the nonpolar continental land area on Earth, they are found primarily in cool, moist regions of the Northern Hemisphere (the north-central United States and north-central Europe extending into Russia) and in sub humid or Mediterranean climatic regions of both hemispheres (western Africa south of the Sahara, North-eastern Brazil, and Southern Australia). The principal agricultural crops grown on Alfisols are corn (maize), wheat, and wine grapes.

Table 2: Land use and soil categories within Ogbomoso watershed

QSWAT Code	**Description**	**Percentage within Watershed**
FOEN	Evergreen Niddle-Leaf Forest	78.4%
SHRB	Shrubland	19.56%
SAVA	Savana	1.88%
MIGS	Mixtures of Grassland and Shrubland	0.07%
Lf64-1a-1955	Alfisol	100%

Model Calibration and Validation

Five years daily satellite-based soil moisture data from the ESA Climate Change Initiative (CCI) surface soil moisture (2006-2010) for the region under investigation was used for the SWAT model calibration. For the validation, both the short term *in situ* measurement of daily soil moisture taken at the study area (April – July, 2017) and five years daily soil moisture data from ESA Climate Change Initiative (CCI) surface soil moisture (2011-2015) were used to validate the SWAT model. The model efficiency measure for the calibration of the simulated soil moisture for R^2 , E_{NS}, and D were 0.91, 0.64 and 13 respectively. For the validation, it was found that the model has a strong predictive capability with R^2 , E_{NS}, D values of 0.81, 0.53, 11 and 0.88, 0.84, 8 for the long-term and short-term validations respectively. The statistical model efficiency criteria for both calibration and validation fulfilled the requirement of $R^2 > 0.6$, $E_{NS} > 0.5$ and $D \leq 15\%$ recommended by SWAT developer. The results suggest that SWAT model can reasonably simulate the spatiotemporal variation and trend of the soil moisture in the area. Therefore, the SWAT model may become a good tool to study the regional hydrological variations and the interaction between the land and atmosphere. The three statistical model performance, for the regression coefficient (R^2), the Nash and Sutcliffe efficiency (E_{NS}) and the percentage difference (D) used in the calibration and validation procedure for the soil moisture are given in Table 3 below.

Table 3: Statistical model performance for the calibration and validation procedure

Procedure	**regression coefficient (R^2)**	**Nash and Sutcliffe efficiency (E_{NS})**	**percentage difference (D)**
Calibration	0.91	0.64	13
Validation with ESA CCI	0.81	0.53	11
Validation with *in situ* measurement	0.88	0.84	8
Standard	$R^2 > 0.6$	$E_{NS} > 0.5$	$D \leq 15\%$

Soil Moisture Observation

The trend in the daily observed soil moisture values during the Rainy season (April-July) in the study area is shown in Figure 4. The soil moisture measurements taken at the Ogbomoso agricultural watershed ranged from 1.98 and 98.35 mm with a mean of 48.64 mm. It was observed to be an increasing trend from the month of April to the month of July. The increasing soil moisture is likely related to the increasing precipitation between April and July which are the rainy season in the study area. This may also be attributed to the decreasing surface air temperature during this period. Figure 5 shows temporal variation of the daily precipitation averaged over the region. Model simulated daily soil moisture values from the sub-basin were compared with the daily observed soil moisture values from the field where the sub-basin is located for this four months period. Figure 6 shows that the model closely follows a similar curve to observed value.

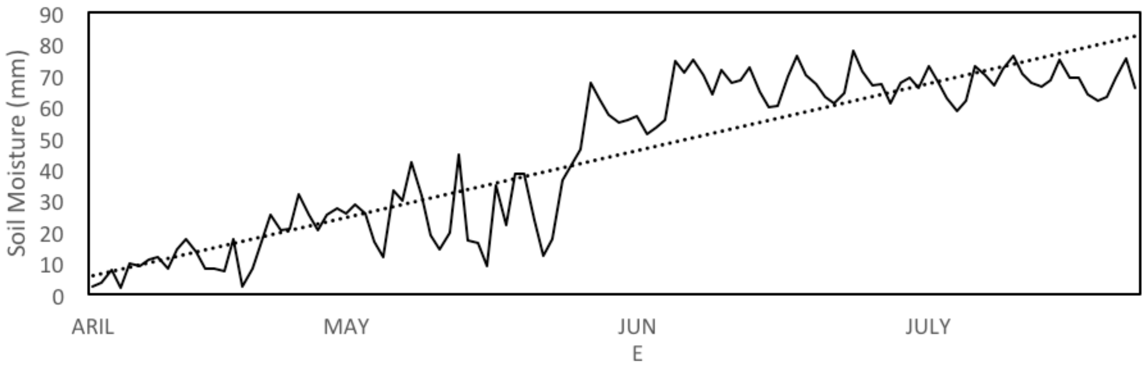

Figure 4: Trend of the temporal variation in the observed soil moisture during the Rainy season (April-July) in the study area

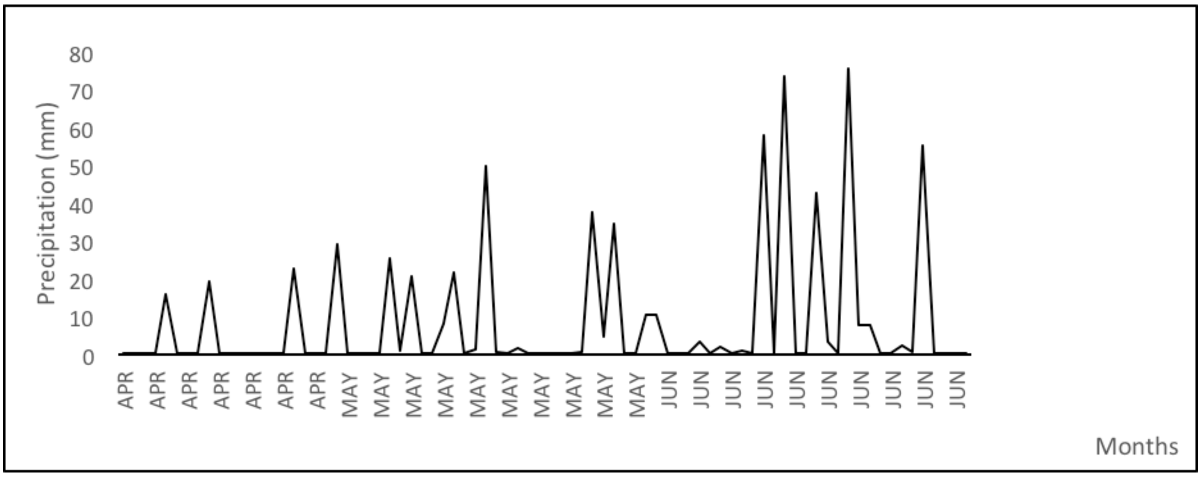

Figure 5: Precipitation distribution at the watershed during the rainy season.

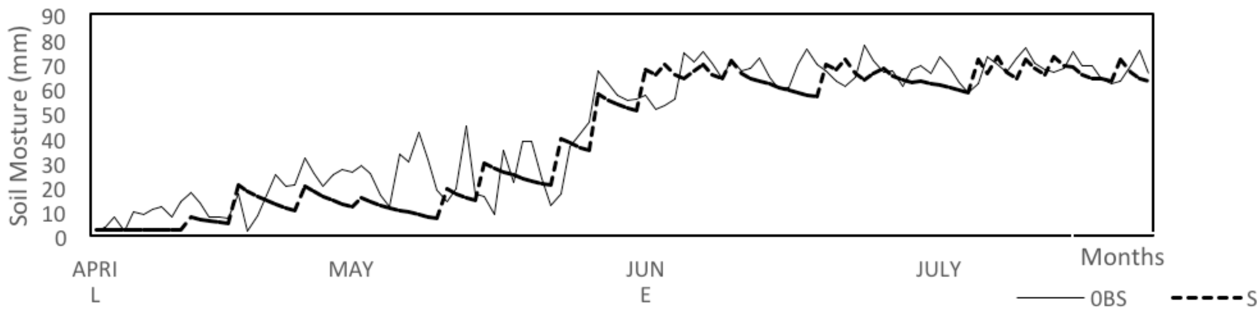

Figure 6: Comparison between daily means of observations and SWAT simulated soil moisture.

Soil Moisture Simulation

During simulation, the first 5 years of the weather input were used as a warm up period. Therefore, the SWAT was used to simulate the soil moisture in the Ogbomoso watershed for 34-year period (1984-2017). Figure 7 shows the temporal variations of soil moisture in the sub-basin of Ogbomoso watershed over the last 34 years. A slightly decreasing trend in the variation of the soil moisture was observed during this 34-year period.

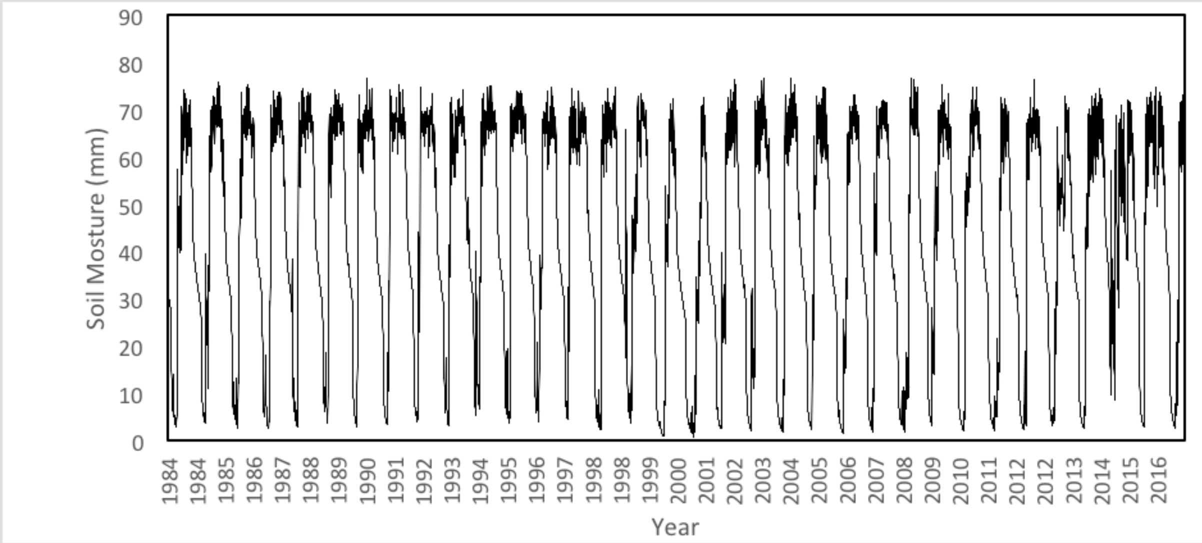

Figure 7: The 34-year soil moisture simulated by SWAT over Ogbomoso watershed

Four years (2008-2011) daily simulated soil moisture values from the sub-basin were compared with the ESA CCI satellite-based daily soil moisture (Figure 8) in order to calibrate the model. The two soil moistures data correlated well. The comparison showed a similar pattern when four years (2012-2015) daily simulated soil moisture values from the sub-basin were compared with the ESA CCI satellite-based daily soil moisture (Figure 9) for the validation.

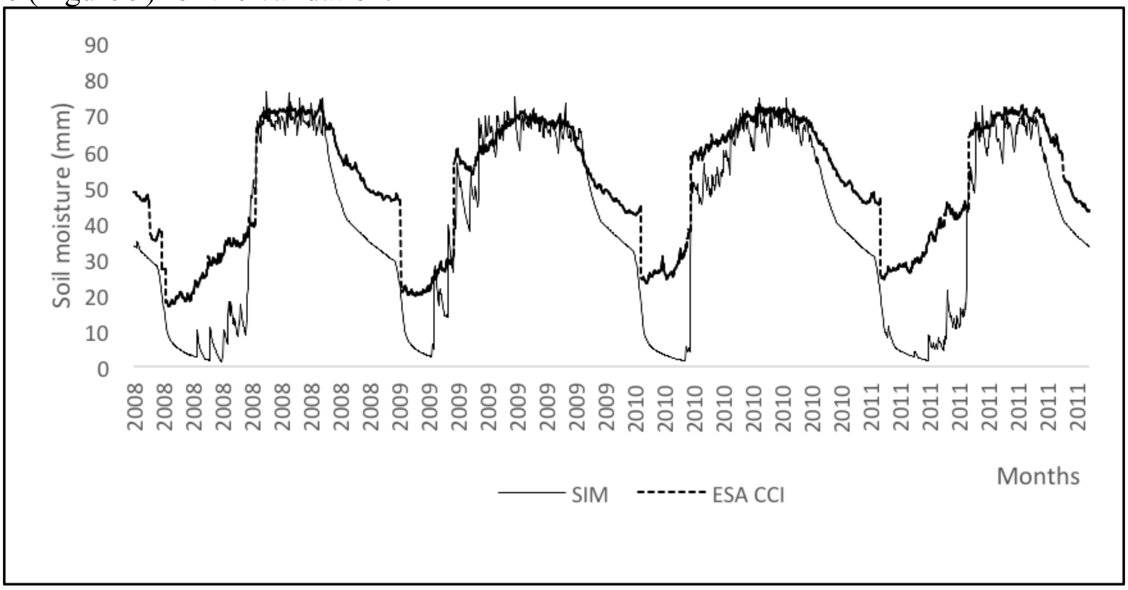

Figure 8: Comparisons between daily means of SWAT simulated and ESA CCI soil moistures (2008-2011)

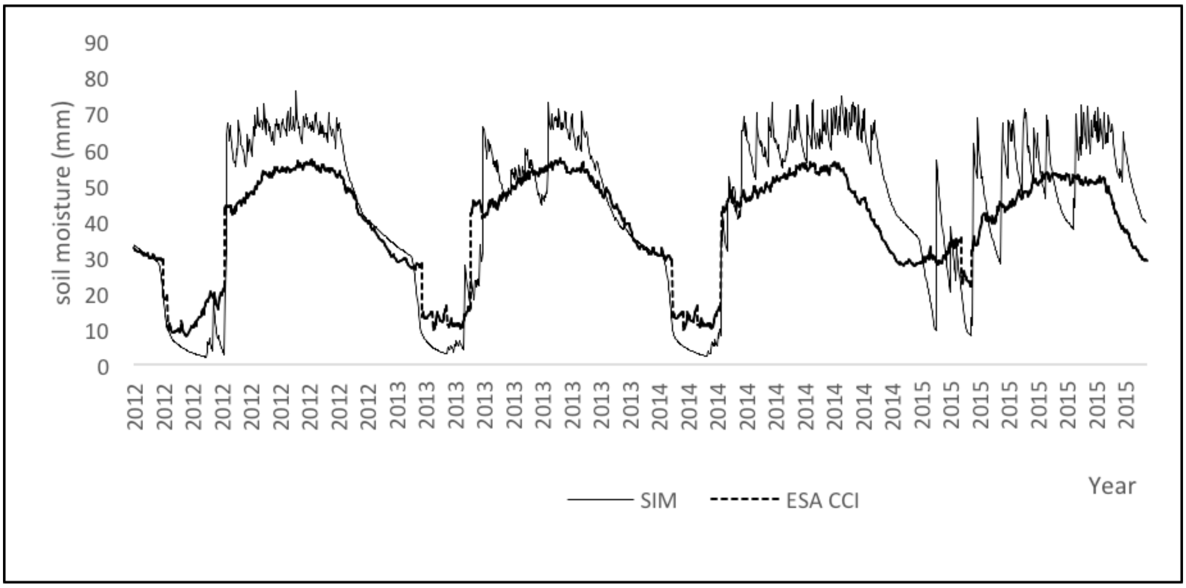

Figure 9: Comparisons between daily means of SWAT simulated and ESA CCI soil moistures (2012-2015)

The pronounced discrepancies between daily simulated soil moisture and ESA CCI satellite-based values in Figure 8 and Figure 9 could be attributed to physical and hydraulic properties associated with the soils, such as soil texture, rainfall, and hydraulic conductivity, but also land cover and land management practices in place. Furthermore, the seasonal variation of the SWAT simulated soil moisture for year 1984, 2000 and 2016 were compared as shown in Figure 10. The seasonal variations for the simulated soil moisture follows the same pattern for 1984, 2000 and 2016. The soil moisture reduces gradually from January to the month of March. The soil moisture begins to pick up in April being the onset of the raining season and continue till mid October when it begins to reduce again. Figure 10 shows that spatial and temporal variability of soil moisture is mainly due to the distribution of precipitation in the area.

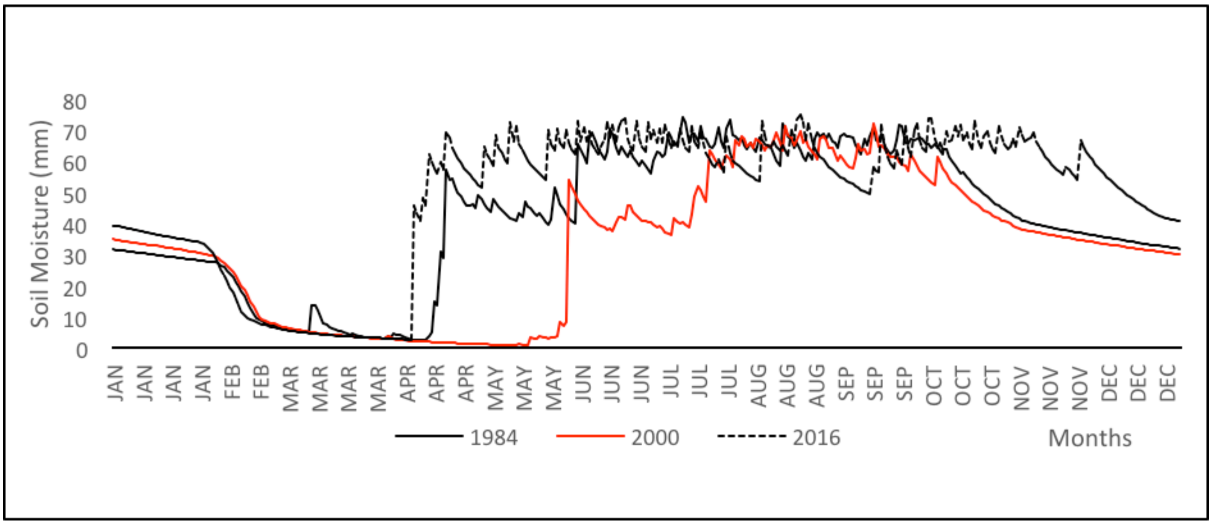

Figure 10: Seasonal variation of the simulated soil moisture

Forecasted Soil Moisture

Soil moisture was projected under the RCP8.5 scenario which assumes high population density, relative slower growth income, moderate technological advancement and improvement in energy intensities (Riahi *et al.,* 2011). This scenario leads to increased energy demands and greenhouse gas emission in the long term absence of climate change regulations and policies. RCP8.5 has been classified as the pathway with the highest emission of greenhouse gases (Riahi *et al.,* 2011). Figure 11 shows the temporal variations of forecasted soil moisture in the sub-basin of the Ogbomoso agricultural watershed in the next 20 years. The forecasted soil moisture trend shows a general decreasing trend. This downward trends may also be responding to the generally observed precipitation decrease and temperature rising in the region.

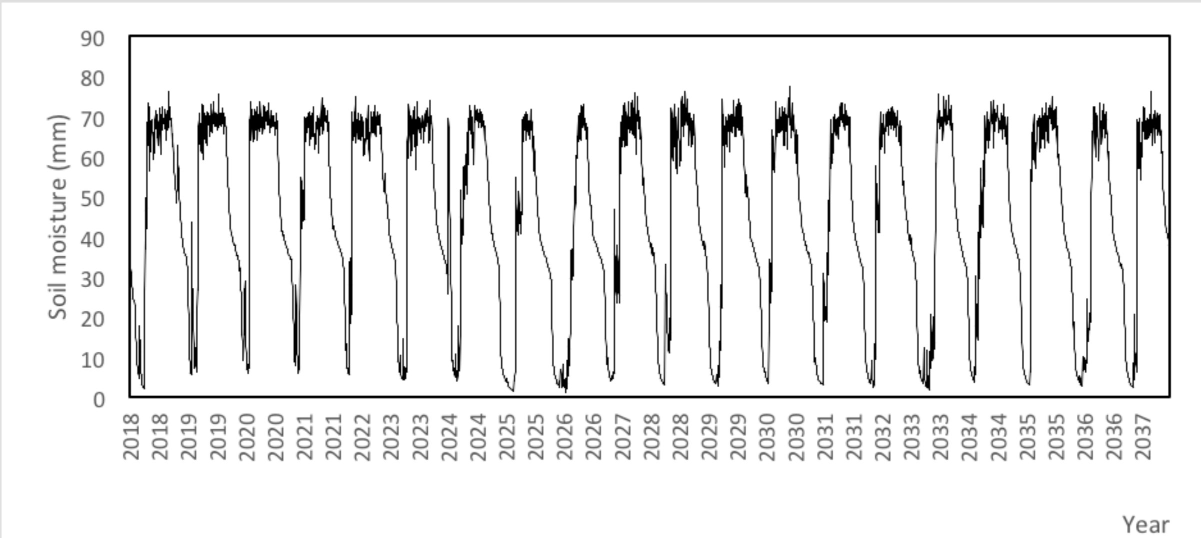

Figure 11: The 20-year soil moisture forecasted by SWAT over the Ogbomoso watershed

Seasonal variation of the SWAT forecasted soil moisture (see Figure 12) show a similar pattern with the seasonal variation of the simulated soil moisture. This further confirms that precipitation plays a vital role in the amount of soil water reserve within the soil.

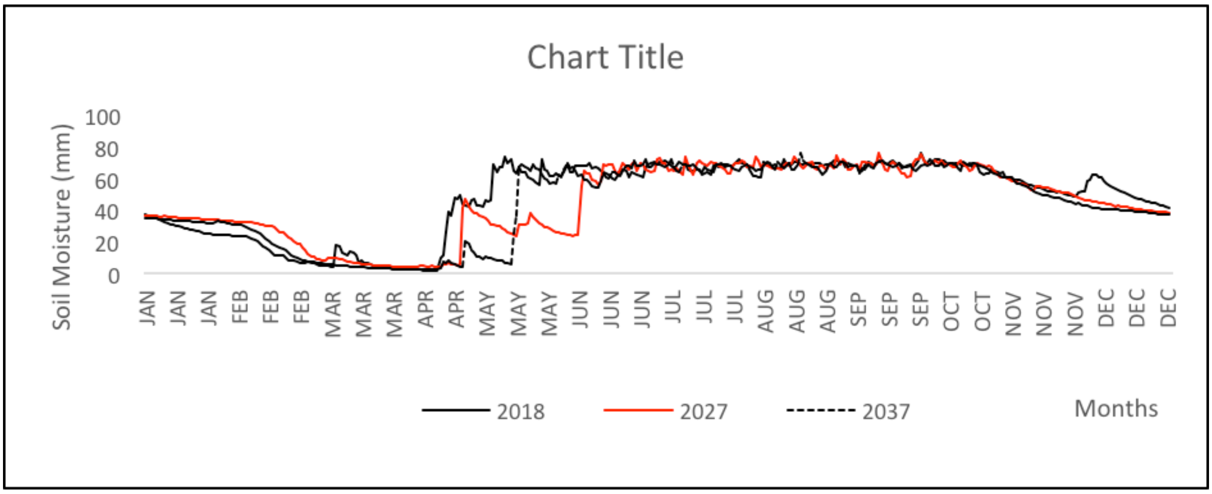

Figure 12: Seasonal variation of the forecasted soil moisture

Conclusion

The soil moisture content within the Ogbomoso watershed, Nigeria was simulated for a 34-year period using the hydrological model, Soil Water Assessment Tool (SWAT). The model was also used to predict soil moisture for a period of 20 years. The SWAT model was calibrated and validated using observed soil moisture. The calibrated SWAT model performed well for the simulation of daily soil moisture. Statistical model performance measures, coefficient of determination (R^2) of 0.91, Nash-Sutcliffe efficiency (E_{NS}) of 0.64 and percentage difference of (D) of 13% for calibration and 0.88, 0.84 and 8% respectively for validation indicating good performance of the model simulations. The variability in both the simulated and predicted soil moistures generally respond to precipitation decreasing and temperature rising in the region. The results suggest that SWAT model can reasonably simulate and forecast the spatiotemporal variation and trend of the soil moisture in the area. Therefore, the SWAT model may become a good tool to study the regional hydrological variations and the interaction between the land and atmosphere. The result of this study could provide essential resource information for watershed managers and aid effective decision making by water resource manager in the area.

Acknowledgement

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Review of Post-Fukushima Electricity Market Reforms in Japan

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Abstract
The TEPCO's Fukushima-Daiichi nuclear power plant accident in March of 2011 is quite influential on the Japanese energy mix and electricity market. Since the accident, the government of Japan has been reforming the electricity supply system in stages to reduce the dependence on nuclear power. The Feed-in Tariff system for renewable energy has been implementing from July 1, 2012 for more than 4 years, and has significantly enhanced the usage of the renewable energy, especially the solar power. Meanwhile, the cost of the renewable energy sources is reduced rapidly. The liberalization to the electricity retail market started since April 1, 2016. Although the achievements of the electricity market reforms are remarkable, it also faces a lot of challenges in the further. In this paper, the current status of the electricity supplied in Japan is reviewed, the basic structure and the deficiency of Feed-in Tariff system of Japan is analyzed. The status of liberalization of electricity retail market is explained.

Keywords: Fukushima, electricity market reforms, Feed-in Tariff system, retail market

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Introduction

After the TEPCO's Fukushima-Daiichi nuclear power plant accident caused by East Japan Earthquake in 2011, the government of Japan has been facing a challenge to reform the energy policy. New reforms of the electricity markets have been carried out after the accident in Japan. Meanwhile, it is more important than before to promote the usage of renewable energy. Therefore the government undertook the Feed-in Tariff system for renewable energy on July 1, 2012. Around the world, the Feed-in Tariff system is one of the widely used incentive systems for stimulating the development of energy sources. In Japan, it greatly promotes the development of the electricity from renewable energy especially the solar power. After that, the full liberalization of retail electricity market has been started since April 1, 2016. Over 4.7% of the Japanese electricity users changed their electricity providers in the last two years.

There are relatively large numbers of recent studies on the reforms of the Japanese electricity market and the designs of the Feed-in Tariff system. Kong Joo Shin and Shunsuke Managi (2017) discussed the consumer satisfaction after the recent liberalization of electricity retail market (Kong Joo Shin & Shunsuke Managi, 2017). Their results indicated that switching rate will be improved by increasing customer satisfaction and underlines the importance of switching. Makiko Nakano and Shunsuke Managi reviewed the regulatory reforms and productivity of the Japanese electricity industry (Makiko Nakano & Shunsuke Managi, 2008). Hiroshi Asano (2006) paid attention to the history and issues of the regulatory reforms of the power system in Japan (Hiroshi Asano, 2006). Arne Klein, Benjamin Pfluger, Anne Held, Gustav Resch, Thomas Faber, Mario Ragwitz discussed the evaluation of different Feed-in tariff design options around the world (Arne Klein, Benjamin Pfluger, Anne Held, Mario Ragwitz, Gustav Resch & Thomas Faber, 2010). Kyoung-Kuk Kim and Chi-Guhn Lee discussed the payoff structure of feed-in tariff systems, and designed the models for the system (Kyoung-Kuk Kim & Chi-Guhn Lee, 2012). Furthermore, some papers payed attentions to the energy policies after the Fukushima accident in Japan. Takeshi Kuramochi (2014) reviewed major energy policies and their targets in Japan, and focused on the problems of the Feed-in Tariff System (Takeshi Kuramochi, 2015). Mika Goto and Toshiyuki Suekoshi reviewed the status, progress, problems related to the reforms of the electricity market in Japan after the Fukushima accident (Mika Goto & Toshiyuki Suekoshi, 2016). Ryoichi Komiyama and Yasumasa Fujii analyzed the post-Fukushima renewable energy policy in Japan's nationwide power grid and found that renewable energy promotion policy underlies the necessity for capacity expansion of inter- or intra-regional power transmission lines in order to realize economical power system operation (Ryoichi Komiyama &Yasumasa Fujii, 2017).

However, only a few studies focused on the current status of the electricity market deregulation and the problems of power system in Japan. This paper will first review the current status of the electricity supplied in Japan in recent years. Then analyze the basic structure of Feed-in Tariff system, discuss the problems of the Feed-in Tariff system of Japan. Lastly, this paper will review the electricity system reforms after TEPCO's Fukushima-Daiichi nuclear power plant accident.

The Status of the Electricity supplied in Japan

In Japan, energy supply was 96% dependent on the overseas import. The energy security is consider as an important challenge to the government. The Fukushima accident led to the operation suspension of the nuclear power plants, which accounted for around 30% of the electricity generations before the accident. The Figure 1 showed the composition of annual electricity generated from 2005 to 2015 in Japan. In 2005, the electricity from nuclear power plant accounted for 30.8% of the electricity generation. In 2013, the nuclear energy accounted for around for only 1% of the electricity generation, while over 70% share of electricity generation depended on the LNG (Liquefied nature gas) energy and Coal energy in Japan. In 2014, there is no electricity generation comes from nuclear power. On August 11, 2015, Sendai nuclear power plant of Kyushu Electric Power Company restarted the operation. As a result, the nuclear energy accounted for around for 1.1% of the Japanese electricity generation (Figure1) in 2015. The share of the renewable energy electricity has increased in 2015 because of the incentive policy.

Moreover, after the Fukushima accident, above 40% share of the electricity generation was from LNG-fire (Figure1). Japan is the biggest LNG and Coal importers in the world. However, the LNG import price in Japan and some Asia countries were still taller than the Europe. Japan's LNG imports increased from 70.0 million tons in 2010 to 87.3 million tons in 2012. Meanwhile, import payments for LNG were 3.5trillion yen in 2010. However, in 2014 import payments for LNG were 7.9 trillion yen (Ryoichi Komiyama and Yasumasa Fujii, 2017).

Since the Fukushima accident, the Japanese people have strong concerns over the safety of nuclear power plant. The local Governments where nuclear power plants are located do not agree to the restarts of the nuclear power plant. The Kashiwazaki-Kariwa nuclear power plant which is the world`s largest nuclear power plant of the Tokyo Electric Power Company is locate in Niigata. The governor of Niigata said that “There can be no discussions about a restart without reviewing” in the gubernatorial election. In addition, some Japanese economists also strongly opposed the restarting operation of the nuclear power plant because the economic effect of nuclear plant was not great (Toudou Fumiaki, 2016). For these reasons the electricity from the renewable energy maybe play an important role in the electricity market in the future.

Japan’s energy policies have changed greatly after the Fukushima accident. On April 11, 2014, the government of Japan decided to approve the new Strategic Energy Plan as the basis for the orientation of Japan’s new energy policy. In the Strategic Energy Plan, the principles for the Japanese energy policy is 3E+S, foremost ensure stable supply (“Energy Security”), and realize low cost energy supply by enhancing its efficiency (“Economic Efficiency“) on the premise of “Safety.” Moreover, it is also important to make efforts to pursue environment suitability (“Environment”).

Following the Strategic Energy Plan, which the Cabinet approved in April 2014, the Ministry of Economy, Trade and Industry established the Long-term Energy Supply and Demand Subcommittee under the Strategic Policy Committee of the Advisory Committee for Natural Resources and Energy. The Long-term Energy Supply and Demand Outlook has been drawn out by the Subcommittee in July, 2015. In the energy mix, the targets of renewable energy is 22-24% by 2030.

Renewable energy sources can be used in heat generation, electricity generation and biofuels (Arne Klein, Benjamin Pfluger, Anne Held, Mario Ragwitz, Gustav Resch & Thomas Faber, 2010). Because the cost of electricity from some types of renewable energy sources such as solar energy are too high, the electricity from the renewable energy accounted for under 1% share of the electricity generated in Japan before the 2009. To complete the targets of renewable energy in energy mix, the incentive policies for improving the usage of renewable energy sources are very important.

The Renewable Portfolio Standard system (RPS) has been started as a supporting policy to encourage renewable energy electricity generation since 2003 in Japan. The Renewable Portfolio Standard system is a program which mandates the power supply companis to purchase a fixed percentage of electricity from renewable energy sources, and has been taken place by the Feed-in Tariff system in July 2012. The Feed-in Tariff systems are incentive policies for the introduction of renewable energy which designed to accelerate investment in renewable energy an energy supply policy by offering long-term purchase agreements. These purchase agreements are typically offered within contracts ranging from 10-25 years. It provides investors with a "tariff" for electricity generated from renewable energy sources that is fed into the power grid. The Public Utility Regulatory policies Act of the U.S in 1987 is considered to be the first Feed-in Tariff system in the world (Kyoung-Kuk Kim & Chi-Guhn Lee, 2012). In Germany, the Feed-in Tariff system under the Renewable Energy Sources Act increased the share of Renewable Electricity generation from 3.6 % in 1990 to 30 % in 2015. The basic structure of the Japanese Feed-in Tariff system will be reviewed as follows.

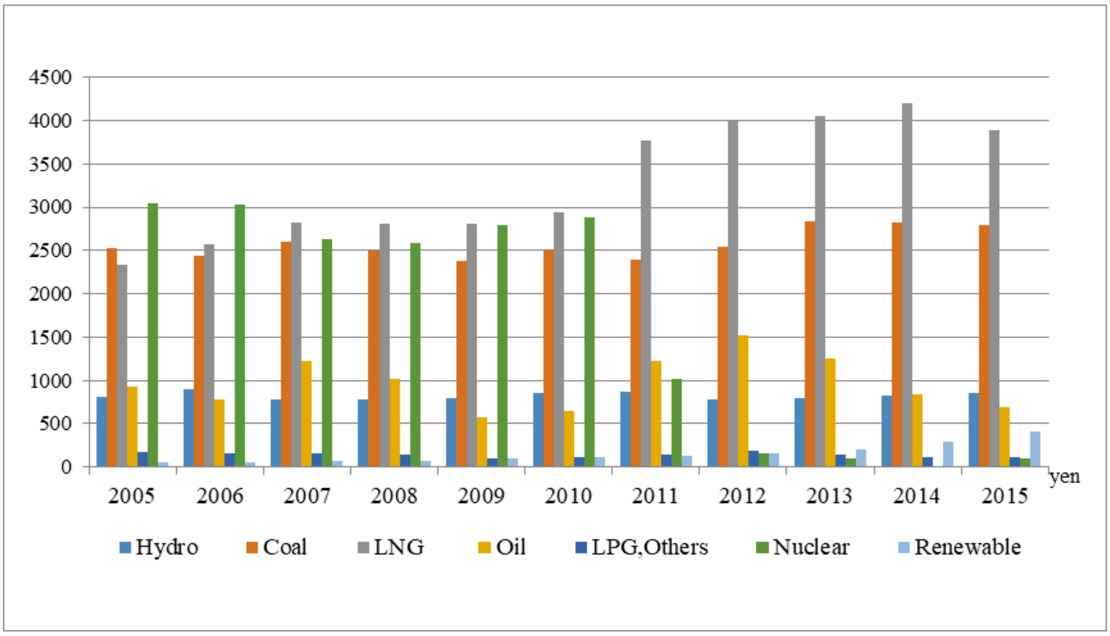

Figure 1: Composition of annual electricity generated in Japan (Unit: 100M kWh)
Source: Federation of Electric Power Companies of Japan.

The Feed-in Tariff System in Japan

In order to promote the introduction of renewable energy sources, the government of Japan approved the “Act on Purchase of Renewable Energy Sourced Electricity by Electric Utilities” at the 177th session of the Diet. Under the Act, the Feed-in Tariff system enacted on July 1st, 2012. The term “Renewable Energy” as used the Feed-in Tariff system of Japan means the following energy sources: sunlight, wind power, hydraulic power, geothermal power, biomass, and energy sources other than crude oil, petroleum gas, natural gas, Coal, and products manufactured therefrom, which are provided for by Cabinet Order as being recognized as perpetually usable as energy sources for electricity (Minister of Economy Trade and Industry, 2014).

The Japanese Feed-in Tariff system obliges electric utilities purchase electricity generated from renewable energy on a fixed period contract at a fixed price. However, the electric power utilities are permitted to refuse to connect them to power grids if they have justifiable reasons. The Minister of Economy, Trade and Industry (METI) determine the Procurement Price and the Procurement Period for each type of renewable energy source every year in order to provide sufficient incentives for investors.

The key point of the systems is the “tariff level”. In Japan, the Procurement Price is based on the price that enables the supply of renewable energy electricity to be conducted stably, and the expenses recognized as ordinarily required, the status of the renewable energy electricity, reasonable profits for the producers of renewable energy electricity. Moreover, the Procurement Period should be based on the time of the beginning of the supply of electricity by the renewable energy power generation facility and the time of the renewal of the important part of the facility (Arne Klein, Benjamin Pfluger, Anne Held, Mario Ragwitz, Gustav Resch & Thomas Faber, 2010).

In addition, in the Agency for Natural Resources and Energy, the Calculation Committee for Procurement Prices was established in order to deside the Procurement Price. There are five members in this committee who are appointed by the Minister of Economy, Trade and Industry among persons who have expert knowledge and experience concerning electricity business or economy.

Moreover, the Minister of Economy, Trade and Industry should designate a general incorporated association, general incorporated foundation, or any other corporation as the Expense Sharing Coordinating Body who grants Subsidies to electricity utilities. According to the Article 9 of the Act, the amount of Subsidies obtained by multiplying the quantity of renewable energy electricity an electricity utility produced under a specified contract by the Procurement Price.

Furthermore, the Expense Sharing Coordinating Body collects payments from electricity utilities. According to the Article 12 of the Act, the amount of payments is based on the amount obtained by multiplying the quantity of electricity an electricity utility supplied to electricity users by the unit price of payment in the business year. The unit price of payment shall be determined by the Minister of Economy, Trade and Industry every year based on the amount of electricity per kilowatt-hour, which is obtained by dividing the amount which is obtained by adding the estimated amount of Administrative Expenses to the total amount of the estimated amount of Subsidies, by the total quantity of electricity all electricity utilities are estimated to supply in said business year.

What is more, according to the Article 16 of the Act, electricity utility should demand the electricity users pay surcharges in order to fund the Payments to the Expense Sharing Coordinating Body. The amount of surcharges is based on the amount obtained by multiplying the quantity of electricity which electricity utility has supplied to electricity user by the unit price of payments. In addition, The Surcharge rate is shown in the following formula.

> The Surcharge rate = (Purchase cost - Avoidable costs + Administrative expenses)/ (Amount of electricity sold in said year)

The surcharge rate which added to the electricity charges for the Feed-in Tariff system in 2016 was 2.25yen/kWh, which was 0.22 yen/kWh in 2012. In 2013, the surcharge was 0.35 yen/kWh. In 2014, it was 0.75 yen/kWh. In 2015, the surcharge was 1.58 yen/kWh. The burden of surcharge for Japanese electricity users may become a serious problem in the further.

The Problems of The Feed-in Tariff System of Japan

Five years have passed since the enactment of Feed-in Tariff system of Japan in July 2012, the Figure 1 shows the outstanding achievements of the policy. Meanwhile, the Procurement Price is reducing every years, especially the photo-voltaic power. The Table1 indicates the Procurement Price and Procurement Period of renewable energy from 2012 to 2017 in Japan. The Procurement Price of electricity generated by photo-voltaic power (10 kW or more) for non-household customers was about 22 yen/kWh in 2017, which was 43yen/kWh in 2012. The Procurement Price of Electricity generated by photo-voltaic power for household customers (10 kW or less) was 42yen/kWh in 2012, which was 28yen/kWh in 2017. However, the Procurement Price of other types of the renewable energy electricity was almost staying the same.

As explained above, the mechanisms of the Feed-in Tariff system is different around the world. The design of tariff level is the most important part of the policy. In other words, the determining procures of the procurement price is the key point of the policy. One possibility is to set the tariff level based on the electricity generation costs from renewable energy. Alternatively, the tariff level also can be based on the avoided external costs by electricity generation using renewable energy (Arne Klein, Benjamin Pfluger, Anne Held, Mario Ragwitz, Gustav Resch & Thomas Faber, 2010). The system has been classed into two broad categories (Makbul A.M. Ramli & Ssennoga Twaha, 2015). One is market independent Feed-in Tariff system, the other is market dependent Feed-in Tariff system. Market dependent systems are those the payment is dependent on the electricity price.

Meanwhile, in the market independent Feed-in Tariff systems, the payment is free from electricity price. Under the Act, tariff level of the Feed-in Tariff system in Japan is based on the reasonable profits for the producers of renewable energy electricity. However, after the opening of the retail market in 2016, the introduction of market dependent Feed-in Tariff system will be an important measure for the development of the renewable energy sources.

		Solar			Wind		
		Output below 10kW		Output above 10kW	Output below 20kW	Output above 20kW	
		Personally installed facilities	together with private power generation facilities and the like			Off-shore wind power facilities	Other than off-shore wind power facilities
Procurement Period		10 years	10 years	20 years	20 years	20 years	20 years
Procurement Period	FY 2012	42.00	34.00	43.20	59.40		23.76
	FY 2013	38.00	31.00	38.88	59.40		23.76
	FY 2014	37.00	30.00	34.56	59.40	38.88	23.76
	FY 2015	33.00	27.00	31.32 29.16	59.40	38.88	23.76
	FY 2015	31.00	25.00	25.92	59.40	38.88	23.76
	FY 2017	28.00	25.00	22.68	59.40	38.88	23.76 22.68

Table1. The Procurement Price and Procurement Period from 2012 to 2017 in Japan, Unit: yen/kWh(Source: Tokyo Electric Power Company)

By the end of June 2016, newly installed generation capacity which certified by the Feed-in Tariff system reached about 87 million kilowatts. However about 79 million kilowatts of which is from photo-voltaic energy. Therefore, it is necessary to take measures to promote the introduction of other categories of renewable energy. Further, because the improving of the usage of renewable energy will likely be a burden on electricity users because of the surcharge in the electric bills. The government should seek a balance between the investors and electricity users when Procurement Price is determined.

Another problem is the access for renewable energy electricity to power grid. On September 24, 2014, Kyushu Electric Power Company announced that they would suspend responding to new applications from renewable energy producers. After the Kyushu Electric Power Company, the Hokkaido Electric Power Company, Shikoku Electric Power Company, and Tohoku Electric Power Company all announced the similar decisions. One of the reasons is the amount of the applications was larger than the acceptable capacity of utility companies, and it was difficult to maintain a stable electricity supply due to an imbalance of supply and demand. To solve the problem, the reforms of the electricity system in Japan and the cross-regional coordination of transmission operators is promising. Moreover, since the output from renewable energy is unstable, policies to enhance transmissions and storage facilities is essential to the introductions of renewable energy.

The Reforms of the Electricity System in Japan.

Until the 1990s, public utilities such as gas industry, electricity industry, telecommunication industry, rail industry, were vertically integrated, sometimes state-owned, and franchise monopolies. But the development of technology and growing evidence of the beneficial effects of liberalization of electricity markets make more and more countries begin the deregulation of the electricity industries. The market competitions may produce a better allocation of resources and greater effectiveness in the electricity supply services (David M.Newbery, 2002). The liberalization of electricity market began in the 1990s in the European countries and the U.S.

In Japan, nine regional electricity companies (Tokyo Electric Power Company, Tohoku Electric Power Company, Hokkaido Electric Power Company, Chubu Electric Power Company, Hokuriku Electric Power Company, Kansai Electric Power Company, Chugoku Electric Power Company, Shikoku Electric Power Company and Kyushu Electric Power Company) were established in 1951 during American occupation. Okinawa Electric Power Company was established after the return of Okinawa in 1972. Under the “regional monopoly power system”, the ten electricity company have the responsibilities for supplying electricity to each region. As of today, the ten vertically integrated electricity companies even control most part of electricity generation, transmission, and distribution networks in Japan. Until 2016, only electricity users with the contract over 50kW can choose their electricity providers (Kong Joo Shin & Shunsuke Managi, 2017).

The Japanese electricity industry has experienced several regulatory reforms since the mid-1990s. In 1995, the first deregulation was started after the bubble economy of the early 1990s in order to increase the efficiency of utility management (Hiroshi Asano, 2006). Through the revision of the Electricity Utility Industry Law, competitive bidding systems was implemented in the wholesale electricity market. The special electric utilities have be established and the Independent Power Produce (IPP) were allowed to enter the electricity industry. Partial liberalization of retail markets was introduced in 2000. The retail market was opened for customers with a contracted supply of 2000 kW or above. The transmission grids which owned by the vertically integrated electricity companies were also made available for use by new electricity suppliers (Hiroshi Asano, 2006).

Furthermore, the amendment of the Electricity Utility Industry Law in 2003 stipulated the extension of the boundary of liberalization. “The markets for maximum power demand over 500kW and over 50kW were liberalized from April 2004 and April 2005” (Makiko Nakano & Shunsuke Managi, 2008). What is more, the wholesale power exchange market (Japan Electric Power Exchange, JPEX) was established in 2003.

Metropolitan area	Number(ten thousand)	Switching rates %
Hokkaido Electric	14.6	5.3
Tohoku Electric	10.3	1.9
Tokyo Electricity	163.3	7.1
Chubu Electric	24.4	3.1
Hokuriku Electric	1.8	1.5
Kansai Electric	60.6	6.1
Chugoku Electric	16.3	0.5
Shikoku Electric	2.5	1.3
Kyushu Electric	16.3	2.6
Okinawa Electric	0	0
Japan	295.4	4.7

Table2 .The switching rates after the liberalization of retail business

After the Fukushima-Daiichi accident, in order to establish a stable electricity supply system, the Japanese government is undertaking the new electricity system reform in stages and plans to complete this reform by 2020. The Cabinet approved the outline about the reforms of the electricity system in Japan on April 2, 2013. According to this outline, the purpose of the new reforms of electricity system have three points as follows. a. Securing the stable supply of electricity. b. Increasing the electricity markets efficiency. c. Expanding choices for consumers and business opportunities.

Furthermore, in order to achieve these aims, the electricity system reform is associated with the development of business. Therefore, the electricity system reform has be divided into three stages. The first stage is the establishment of the Organization for Cross-regional Coordination of Transmission Operators, and it was finnished by 2015. The second stage is the liberalization of electricity retail market. The third stage was the securing of neutrality of transmission and distribution.

Currently, the second stage has been started. The full liberalization of electricity retail business has been started since April 2016 with the amendment of the Electricity Utility Industry Law. Until the March 2017, about 2.95 million households had changed their electricity companies in Japan. The average switching rates was 4.7%. The Tokyo Electricity Power Company metropolitan area had the highest share of switching rates 7.1% (Table2). Okinawa Electric Power Company metropolitan area had no user change the providers. Compared to the European countries, the switching rate In Japan is relatively low (Kong Joo Shin & Shunsuke Managi, 2017). The ten vertically integrated electricity companies even play the most important role in the electricity retail market in Japan.

That maybe partly due to the transmission grids are even under control of the regional electric companies. The new electricity providers must pay transmission tariffs to the regional electric companies when they use the transmission lines. Therefore, the neutrality of transmission and distribution sector is the most important problem in the future. In addition, the deregulation of the electricity market is consider as a good method to the introduction of the renewable energy electricity, because most of renewable energy electricity companies are new market entrants and they must use the transmission lines of regional electric companies.

Conclusion

Japan is fifth largest energy consumer and the largest importer of the LNG sources in the world. As energy supply is heavily depend on imports, the nuclear power is considered as an important means to ensure the electricity supply. Before the TEPCO's Fukushima-Daiichi nuclear power plant accident, around 30% share of the electricity generation is from nuclear power. Because of the safety problem of the nuclear power, the schedule of the nuclear power plants restarting operation is still not sure. The Japanese policy makers are taking measures to improve the usage of other sources such as renewable energy sources. Furthermore, the deregulation of electricity market in Japan is later than the other developed countries. The regional monopoly power system even control most part of the power system virtually after several of regulatory reforms of the electricity system.

In order to enlarge the usage of the renewable energy electricity and increase the efficiency electricity systems. Incentive policies the renewable energy was started and the Organization for Cross-regional Coordination of Transmission Operators was established. The usage of the renewable energy electricity enhanced significantly since the enactment of the Feed-in Tariff system in Japan. The electricity from the renewable energy sources accounted for 4.7 % of the electricity generation in 2015. But the growing surcharge of this policy will be a burden to the Japanese electricity users.

Further, the full liberalization of electricity retail market has been started since April 2016. The new electricity providers must pay transmission tariffs to the regional electric companies when they use the transmission lines to supply electricity. The transmission cost allocation maybe an important subject in the future.

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Sisters in Sustainability: Gender-Driven Agricultural Initiatives Promoting Socioeconomic, Environmental, and Cultural Sustainability

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Abstract
An increasing number of women are choosing to pursue careers in agriculture. A higher percentage of women are represented among sustainable farmers than are counted among conventional farmers. For example, in the United States, this percentage is 21 percent as compared to 9 percent. The way in which women farmers approach sustainable agriculture is consistent with the feminist ethic of care that encompasses responsibility, nurturing, relationality, and interdependence. These characteristics are expressed in a number of ways on women-owned or operated sustainable farms. Their farms, for example, have fewer acres than those of male farmers; they plant, cultivate, and harvest by hand much more than with heavy equipment; and they only very rarely use inorganic fertilizers. Also, their operations are more diversified. Women who farm also have a record of developing strong networks with their fellow women farmers. Thus, these sisters in sustainability appear to be applying gender-normativity to organic farming, prioritizing relationships and engaging in holistic, systems thinking. They integrate a broad range of relevant factors into their farming practices, such as the environment; food safety, nutrition, and public health; and home, farm, and community socioeconomic improvement. This is a much broader scale of "relevance" than would be considered in conventional agriculture, cultivating not only the social and economic sustainability of the farmer and her family but also of her network and local community. It also protects biodiversity, indigenous knowledge, and environmental sustainability and preserves the cultural sustainability of historical production methods and heritage seed varieties critical to food security.

Keywords: Gender, Agroecology, Ethic of Care, Sustainability, Organic Agriculture, Sustainable Agriculture

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Introduction

An increasing number of women are choosing to pursue agriculture as their occupation. Women's roles and their status in the agricultural sector can vary greatly depending upon their age, their ethnicity, their social class, or the geographic area in which they live (Doss, 2011). For example, women may own or operate their own farms; they may work as paid or unpaid labor on family farms or on other farms or agricultural enterprises; and they may work with crop, livestock, or aquacultural production at subsistence and commercial levels.

Many women, however, are choosing to focus on sustainable[1] farming, and they represent a larger percentage of organic farmers than of conventional farmers. For instance, while women represent 9 percent of all U.S. farmers, that figure rises to 21 percent for all organic farmers (Farnworth & Hutchings, 2009).

The approach taken by women farmers to organic, or sustainable agriculture, is a paradigm shift from the more conventional model strongly associated with masculinity. Sustainable women farmers work with less mechanized, natural methods, and their farms have fewer acres than those of male farmers. Their operations are more diversified. Women who farm also have a record of developing strong networks with their fellow women farmers to share information.

Thus, women, whom in this context these authors refer to as Sisters in Sustainability, appear to be applying gender-normativity[2] to organic farming, prioritizing relationships and engaging in holistic, systems thinking to their farming that integrates a broad range of relevant factors, such as the environment; food safety, nutrition, and public health; and home, farm, and community economic improvement. This is a much broader scale of "relevance" than would be considered in conventional agriculture, a scale that cultivates not only the social and economic sustainability of the farmer and her family but also of her network and local community. It also protects biodiversity, indigenous knowledge, and environmental sustainability and preserves the cultural sustainability of historical production methods and heritage seed varieties critical to food security.

Despite the significant contributions that they make to their families, to their communities, and to society at large, women farmers normally have "less access to land, information, capital and credit, and other inputs than men farmers" (Doss, Meinzen-Dick, Quisumbing, & Theis, 2018). This negatively impacts society at all levels as it undermines economic development by, inter alia, limiting food security and educational prospects (Nierenberg, 2014). Rather than continuing to ignore this unequal access, opportunities for female farmers should be expanded, particularly in the sustainable farming segment where Sisters in Sustainability are enhancing our food systems - socioeconomically, environmentally, and culturally.

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[1] The adjectives "alternative," "sustainable," and "agroecological" are utilized interchangeably herein to describe a particular approach to farming. The term "organic" is **not** limited to **certified** organic farms as certified organic has become a "political, cultural, economic and social construct … located within western ideologies and practices" and is laden with hegemonic overtones that the authors seek to avoid (Farnworth & Hutchings, 2009).

[2] This article does not use the concept of "gender" in the biological sense, but rather in the context associated with social roles and identities as shaped by ideological and other factors (Moser, 1989).

The Data

Women comprise approximately 43 percent of agricultural labor globally (Doss, 2011), and they produce more than 50 percent of the world's food (Akter et al, 2017). These data almost certainly underestimate women's involvement in agriculture: women who work on family farms or who work at home in gardens, with livestock, in food preparation, or in catering often are not reported as agricultural workers (Doss et al., 2018). Notwithstanding the essential role of women in agricultural production, women confront a consistent gender gap in access to productive assets, inputs, and services (Doss, 2011).

For example, women farmers typically lack access to education and extension services and to land and credit. One can see this in the U.S., where, in 2017, the U.S. Department of Agriculture's Farm Service Agency decreased lending to female farmers and farmers of color for the second year in a row (National Sustainable Agriculture Coalition [NSAC], 2018). This funding decrease was larger and relatively disproportionate for this group of farmers vis-à-vis other categories of loan applicants (NSAC, 2018). Because the farmers in this category, a group that the Farm Service Agency categorizes as "socially disadvantaged," often find it difficult or impossible to secure private financing, it can be financially devastating when access to government-supported lending is denied.

Globally, data report that, on average, women are paid less than men with comparable levels of education and experience for equivalent agricultural jobs (Doss, 2011). Average female wages are lower than average male wages in both rural and urban areas, and, even in high-value, export-oriented agro-industries that offer better opportunities for women in developing countries than do traditional agricultural jobs, women appear to occupy a lower percentage of managerial or professional jobs than do men and appear to be replaced by men when company profits increase (Doss, 2011). These data are consistent with reports from the developed world. According to 2011 data from the U.S. Bureau of Labor Statistics, just one out of six full-time U.S. farmers, ranchers, and other agricultural managers was a woman, and only one out of seven principal farm operators in the U.S. was a woman (Faruqi, 2013).

Women also hold a significantly much smaller percentage of agricultural land than their male counterparts in developing regions (World Bank, 2012). Women with land generally have smaller plots of an inferior quality than those held by men, and their rights to these plots are legally less secure (Doss, 2011). Again, this is not unique to the developing world. Female farm operators in the U.S. also hold far fewer acres than their male counterparts (Doss, 2011). Women farmers in Knoxville, Tennessee, for example, operate 15 percent of 912 farms, and the average size of their farms is 15 acres less than the male-average in the State (U.S. Department of Agriculture [USDA] Census, 2012).

In addition to this consistently disparate access to data, education, capital, land, credit, and other inputs, most agricultural R&D programs ignore the unique needs of women farmers (Meinzen-Dick et al., 2011). Conventional agricultural R&D tends to be gender blind or gender biased. Its programs are designed in an environment with "a persistent lack of gender balance among scientists and leadership;" they are focused on the male-oriented activity of producing field crops; and they are disseminated by a largely male extension service to a significantly higher percentage of male farmers (Meinzen-Dick et al., 2011). This gender inequality extracts a price from society as it undermines family and community food security and excludes women from educational opportunities (Asian Development Bank, 2013).

There are additional, critical reasons to address this discriminatory gender-based treatment in the agricultural sector, i.e., reports suggest that female farmers would produce the same yields as their male counterparts given equal access to productive resources and services: with these comparable resources, female farmers could lift 100-150 million people out of hunger (Nierenberg, 2014). Indeed, many studies go further and estimate that reducing inequalities between male and female farmers could potentially *increase* agricultural productivity by as much as 10–20 percent in certain geographical areas (Meinzen-Dick et al., 2011).

If one believes, as these authors do, that addressing gender-based discrimination in the sector is a high priority, then alternative, sustainable agriculture appears to be one option that is providing "spaces of empowerment for women" to participate more equitably in farming (Trauger, 2004). The global increase of women in the sustainable farming sector may not be related to a sex- or gender-specific characteristic, but rather may be a response to the gender bias that prevails in conventional agricultural models. Whatever the catalyst, however, sustainable agriculture may substantially lower the barriers to entry to agricultural careers for women vis-à-vis conventional agricultural models. A number of reasons have been posited for this relative ease of access, i.e., it: (1) reduces capital and land requirements, (2) provides a "level" playing field for all new market entrants given the relatively "new" nature of the segment; (3) provides opportunities to acquire the skills necessary for success, (4) improves farm income, and (5) allows farmers to locate in urban and suburban areas as opposed to more remote, rural regions (Pilgeram & Amos, 2015).

The Impact of Women as Sisters in Sustainable Farming

While it may not, again, be a gender-specific approach, these Sisters in Sustainability appear to farm differently as a group than do their male counterparts. They apply a holistic, integrative approach to farming (Stonehouse, 2003) that explicitly considers the socioeconomic, environmental, and cultural dimensions of their activities, activities in which many women are motivated to engage in order to nourish themselves, their families, and their communities (Jarosz, 2011). These dimensions are examined in more detail below.

- **The Socioeconomic Dimension**

Women often exhibit the feminist ethic of care when they farm sustainably (Jarosz, 2011). This ethic encompasses values traditionally associated with women, such as responsibility to self, family, and community; sensitivity; empathy; and interdependence (Gilligan, 1982). In an agricultural setting, this expresses itself in a number of ways that distinguish the practices and motivations of many female farmers from many of their male counterparts.

For example, women in alternative agriculture in the U.S. define their work "as centered upon nourishing themselves and others" (Jarosz, 2011); their roles as mothers and homemakers and their income-generation and community development work are inextricably interconnected. Sustainable farming provides opportunities to enhance the health and environment of the families and the communities of these women (Farnworth & Hutchings, 2009). Some Sisters in Sustainability, for example, see alternative farming as a "'political [and] revolutionary [activity that promotes] food sovereignty'" and as "'a mission of supporting Black and underserved farmers around the country'" (Richards, 2018). Their motivations are not solely economic, but rather they prioritize their own social and economic sustainability as well as those of their networks and local communities.

Because their interest in farming is multi-faceted, while the interest of men who farm typically is not (Sachs et al., 2016), Sisters in Sustainability often diversify their farm operations. They do this in a variety of ways, combining traditional crop and/or livestock production with community supported agriculture; with production and sale of farm-related products such as knitted clothing, soap, or prepared food; and with involvement in agritourism operations, such as cooking schools, inns, and/or restaurants (McColl, 2018).

Female sustainable farmers also share a strong land care ethic and a commitment to providing alternatives to commodified food and to food security through the development of smaller scale sustainable food networks. These women often participate in an economy that includes barter, community supported agriculture, and farmers' markets (Jarosz, 2011). These outlets express their ethic of care for their community in the public sphere, providing alternatives to conventional food outlets and allowing women farmers to develop more meaningful social relations with their customers (Jarosz, 2011).

Educational goals also motivate these Sisters in Sustainability. They seek to provide consumers with a connection to the land and to educate them about their food supply, offering, for example, cooking classes (Jarosz, 2011) and courses on gardening (Richards, 2018). They also have a strong desire to improve themselves and to learn. The relational aspect of the feminist ethic of care exhibited by women sustainable farmers expresses itself here in their record of developing strong group relationships to share information with their fellow women farmers and of creating and engaging in peer-to-peer networks (McColl, 2018). These networks can be formal, such as the Women Food & Ag Network, a nonprofit that seeks to support women in ecological agricultural systems, and the Women's Agricultural Network, a service associated with the University of Vermont that is designed to increase the number of women in agricultural-related businesses. There also are the more informal networks, such as the Green County Area Women in Sustainable Agriculture, more commonly known as the Soil Sisters, a group in the U.S. state of Wisconsin that is loosely organized and that serves as a support, political action, and marketing group (McColl, 2018). These associations are critical for women who farm as they often lack access to more formal educational channels such as higher education or extension services (Food and Agriculture Organization of the U.N. [FAO], 2010-2011).

- **The Environmental Dimension**

Sustainable agriculture is characterized by production systems that support the health of soils and ecosystems adapted to local conditions (Altieri, 2018). The Sisters in

Sustainability who practice this form of farming seek to achieve harmony with nature and to protect land for future generations. In the tradition of Rachel Carson (Carson, 2002), many women who farm sustainably focus on ecologically-sound, nonchemical agricultural methods and technology or those that use less persistent chemicals. In North America, for example, women engaged in sustainable farming rarely apply inorganic fertilizers; studies indicate that female farmers are less likely than their male counterparts to engage in chemical-intensive production (Richards, 2018). Further, women in the organic sector also only very sparingly use heavy machinery and perform fieldwork such as planting, cultivating, and harvesting by hand (Paul & Fremstad, 2016). While many have made a deliberate choice to farm this way, some argue that sustainable female farmers employ these practices due to their lack of access to capital-intensive agricultural assets like machinery (Trauger, 2014). However, if these women are able to gain access to heavy farm equipment, they often are not trained to operate and/or maintain it and either must, or choose to, enlist or hire men for these tasks (Farnworth & Hutchings, 2009).

Regardless of the motivation, however, these practices result in positive environmental outcomes. As do the economic choices made by many Sisters in Sustainability. When sustainable women farmers produce for local markets or work with ecologically-responsible distributors, they are acting to reduce lengthy food chains and minimize their carbon footprints. As one example, organic female farmers in the Western U.S. are able to choose Veritable Vegetable to move their food from farm to market. Veritable Vegetable is an all-women owned organic produce distributor that operates a fleet that includes hybrids tractors and hybrid refrigeration units producing nearly zero emissions and that utilizes efficient routing, trailer skirts, and sophisticated on-vehicle technologies such as tire pressure monitoring and inflation systems and wind resistance inserts to reduce fuel consumption (Straight, 2012).

Local market sales also allow alternative female farmers to address animal welfare issues related to transportation before slaughter (Farnworth & Hutchings, 2009). The feminine ethic of care expressed by sustainable women farmers is evident in their attitude toward farm animals. One observer noted in interviews with farmers that "women … in agriculture showed a clear preference for working on organic and small farms, which are more likely than factory farms to reflect the values of animal welfare, human health, and environmental sustainability. … [and that women were] generally more humane in their treatment of animals" (Faruqi, 2013).

The motivations of women who farm sustainably also impact their physical environments. The survival instinct has long created a special interconnection between women and agroecological systems. In certain cultural contexts, and in some circumstances, women rely on natural resources to provide food, housing, and clothing for themselves and their families (Bodouroglou & Alarcón, 2014). Their very survival may therefore be dependent upon the conservation and preservation of these resources, and they have developed expertise in the practices and systems that facilitate their sustainability. Even in the developed world, the role that women play in their homes and families, a role that often is assigned primary responsibility for food preparation, provides an interest in the source and quality of their food supply.

- **The Cultural Dimension**

To restate a commonly-used phrase, women who farm sustainably keep the culture in agriculture. Many female farmers are motivated to participate in alternative agriculture to make a life as opposed to making a living (Jarosz, 2011). These women are motivated by the farming lifestyle, making a deliberate choice to live a way of life deeply rooted in their cultures (McColl, 2018).

On some farms, sustainable women farmers preserve historical production methods and land-management systems as well as heritage plant, animal, and aquatic species. Adding heritage Red Devon cattle to an existing herd is one example of this type of activity undertaken by one female farmer in Wisconsin (McColl, 2018). Another example: women in Peru's Potato Park Indigenous Biocultural Heritage Territory strongly contribute to landscape management systems that have evolved over centuries in the harsh Andean environment and that are essential to preserving the Park's local biocultural heritage, products, and services (Sayre, Stenner & Argumedo, 2017).

Women such as those in the Potato Park, and in many other cultures, have considerable knowledge about, and experience with, the management and preservation of indigenous biodiversity reserves and with farming techniques compatible with local agroecological systems. Women in Bangladesh whose organic farming practices rely upon animal traction from indigenous livestock and poultry species of the region for soil management exemplify this dimensional aspect (Farnworth & Hutchings, 2009). In this way, they not only are performing conventional economic activities, but they also are providing ecological services, such as ensuring the conservation of diverse genetic resources (Bodouroglou & Alarcón, 2014).

Also, women tend to farm locally-important crops such as leafy vegetables and sorghum, and they conserve traditional varieties of these and other crops as well as flowers, handicraft crops, and heritage animal species. This is essential to preserving species that are critically important to geographically-bounded food security but that often are ignored and driven out in the interest of commercially-focused conventional agricultural goals (Farnworth & Hutchings, 2009). This has been reported in East Africa, for instance, where tobacco production for export is driving out the cultivation by female farmers of local food crops such as millet and sorghum (Doss, 2011).

Conclusion

To conclude, Sisters in Sustainability are a growing share of what has been referred to as "civic agriculture" rather than capitalist agriculture, in part due to their multi-dimensional, innovative approach to food production systems (Lyson, 2012). As their share grows, so too does their influence: male farmers entering the alternative farming sector may also be embracing the relational, emotional, and interdependent qualities of the feminine ethic of care exhibited by their female counterparts (Elliott, 2015). This has the potential to expand the opportunities for women choosing agriculture as a career as well as for all those with intersecting interactions.

While this concludes these authors' paper, it is not the end of the story of these Sustainable Sisters. It is clear that they are transforming traditionally masculine spaces on farms – socioeconomically, environmentally, and culturally. Promoting these dimensions of agricultural sustainability has the potential to enrich much more than just the global food system.

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Water Resources, Population Growth, and the Environment in Malaysia: An Overview

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Abstract
Water is the basic need for life as well as the essential input for industries. The increasing population and urbanization leads to the highly demand of water consumption which contributes to water scarcity among residential and industrial usage. Water stress is the most crucial environmental challenges experiencing in many nations around the globe. Beside, water shortage an increase to the population would also bring industrialization and urbanization which causes environmental problems which directly affects the quality of the water supply. Population growth have a significant effect on environment in order to meet the sustainable development. This paper reviews and analyse on the trends in water resources, population growth and environment pattern in order to understand the key issues and challenges faces for water resource development in Malaysia. Furthermore, it attempt to examine the linkages between the population, water consumption and environment. The article finally discusses the importance of improving and enhancing existing policies of water resources in order to conserve the nature while promoting sustainable economic growth.

Keywords: Water consumption, Population growth, Environment, Sustainable development

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Introduction

There can be no life without potable water. This need is threatened by increasing population growth which places pressure on water demand for domestic, industrial, and municipal uses. Most if not all industries require water not least of which is agriculture and energy. The most water scarce or stressed areas are typically those with few water resources, high population densities, and high population growth rates (UN, 2007). Population growth means that there is less water per person and those areas with the highest populations and high levels of industry often suffer from the highest levels of water stress and scarcity.

Given the above, cities are particularly vulnerable to water stress and shortages, particularly given that they often undergo continuous urban development resulting in increased water demand (Dash, 2013). From 1950 to 2016, the population living in urban centres grew significantly from 30% to 54.5% (UN, 2016). With this growth trajectory, it is estimated that by 2050, 66% of the global population (roughly 6.2 billion people) will reside in urban areas (UN, 2015). Africa and Asia are two rapidly growing regions. China (additional 292 million urban residents), India (additional 404 million urban residents) and Nigeria (additional 212 million urban residents) will likely account for 37% growth of the world's urban population by 2050 (UN, 2015). The mass migration to cities means has resulted in a near six-fold increase in global water consumption in cities, which is twice the rate of population growth (Guinness and Walpole, 2012).

Malaysia's water is nearly entirely derived from surface water resources such as rivers and reservoirs at 98% (Second National Communication (NC2), Malaysia 2011). The remaining 2% is sourced from groundwater. Malaysia spends most of its valuable water on irrigation, and industrial and domestic purposes (Economic Planning Unit, 2006). As for its non-consumptive uses of water, Malaysia uses it predominantly for hydropower, navigation and recreational activities.

With economic and population growth, the demand for water to sustain life and industries is also rising. This demand is highest for agriculture. In Malaysia, this demand was 54% of the nation's total demand for water in 2010 (Economic Planning Unit, 2010).

In Malaysia, the demand for water is not equal across all states and areas. Some areas suffer from water scarcity while other places have an overabundance of water. In 1998, an El Nino related drought caused severe water stress in Kedah and Penang, and water rationing in Kuala Lumpur and Petaling Jaya for many months, while other states were relatively unaffected.

Malaysia's weather has also become rather unpredictable in recent years with an increasing frequency in dry spells and water crises in Peninsular Malaysia, particularly Malacca and Selangor, and some parts of East Malaysia. For example, the 2002 drought destroyed thousands of hectares of paddy in Perlis and caused water stress in many areas of the country (Chan, 2009).

With this overview of the state of water in Malaysia, this paper reviews and analyses the trends in water resources, population growth and environmental patterns in order to understand the key issues and challenges facing water resource development in Malaysia. Furthermore, it examines the linkages between the population, water consumption and environment. The article concludes by discussing the importance of improving and enhancing existing water resources policies to conserve nature while promoting sustainable economic growth.

Materials and Methods

This study reviews the current state of water resources in Malaysia based on a review of full-text journal articles, reports, and conference proceedings sources from both electronic and non-electronic databases. In addition, the websites of organisations that have researched or address this issue were referred to for related documents and reports. Only documents written in English were considered.

Water Resources

Malaysia is a country with abundant water resources. Groundwater accounts for 90% of the freshwater resources. The renewable water resources are 630 billion m^3 - the summation of surface runoff and groundwater recharge. This translates into an annual average water availability of about 28,400 m^3 per capita. The water resources in Malaysia are summarised in Table 1.

Table 1: Water Resources in Malaysia

Annual rainfall	990 billion m^3
Surface runoff	566 billion m^3
Evapotranspiration	360 billion m^3
Groundwater recharge	64 billion m^3
Surface artificial storage (dams)	25 billion m^3
Groundwater storage (aquifers)	5 000 billion m^3

Source: National Water Resources Study (1982) and Malaysia Water Industry Report (1998)

Streams and rivers with and without impounding reservoirs contribute 98% of total water used in Malaysia. Groundwater contributes the remainder. River flow regimes are irregular and to secure safe yield from surface water sources, storage facilities were constructed. The main reason for the lack of groundwater use in the country is the easy availability of surface water resources; there are over 150 river systems in Malaysia (Abdullah and Mohamed, 1998). The most important source of raw water is direct extraction from rivers, with approximately two-thirds of raw water supply in Malaysia (Table 2) being obtained in this way. It is followed by storage dam and groundwater in the less-developed states of Sabah and Kelantan.

Table 2: Raw Water Resources (2016)

Water Supply Entities	Direct Extraction from River	Storage Dams (Direct)	Ground Water	Total
	Million Litre Per Year (MLD)			
Johor	1,072	664	n.a	1,737
Kedah	1,449	22	n.a	1,471
Kelantan	287	n.a	214	501
F.T. Labuan	69	4	0.0	74
Melaka	424	312	n.a	737
N. Sembilan	489	408	n.a	897
Pulau Pinang	1,064	91	n.a	1,155
Pahang	1,170	31	7	1,208
Perak	1,031	361	n.a	1,393
Perlis	186	71	4	260
Sabah	836	355	30	1,221
Sarawak	1,207	122	n.a	1,328
Selangor	4,661	427	n.a	5,088
Terengganu	485	197	n.a	682
MALAYSIA	**14,431**	**3,065**	**254**	**17,750**

Notes:
1. Volume of raw water extracted may vary for each year due to:

a. Treated water supply and demand

b. Commissioning of new WTPs

c. Upgrading of available WTPs

d. Other environmental factors including weather and pollution

Source: Malaysia Water Industry Guide (2017)

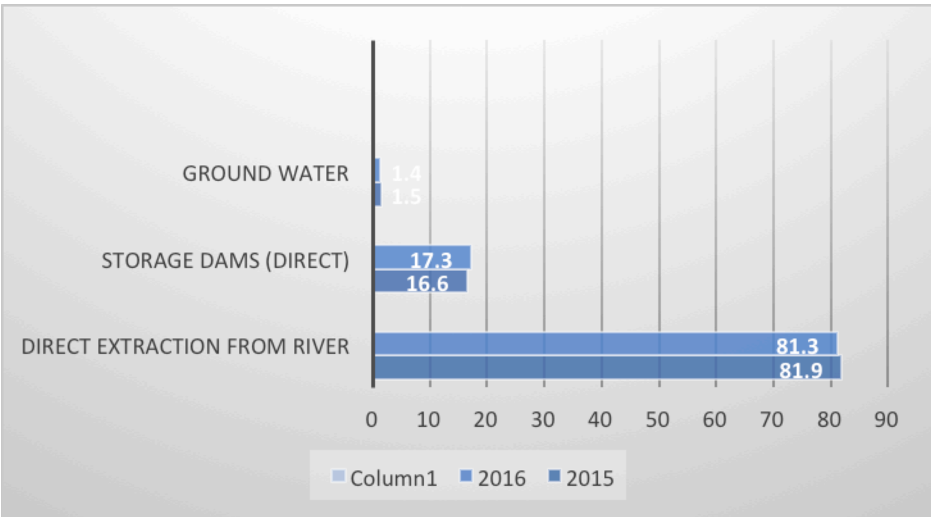


Figure 1: Proportion of Raw Water Resources 2015-2016
Source: Malaysia Water Industry Guide (2017)

Water Supply and Water Coverage

As of 2016, 95.7% of the population was served with clean and treated water supply, rising from 95.5% in 2015. Most states recorded 100% coverage in urban areas - the only exception being Kelantan at 61.7% as stated in Table 3. As a less-developed state, it does not have the financial capacity to improve water supply coverage.

Table 3: Percentage of Urban & Rural Population Served, 2015-2016

Water Supply Entities	% Population Served 2015			% Population Served 2016		
	Urban	Rural	State	Urban	Rural	State
Johor	100	99.5	99.8	100	99.5	99.8
Kedah	100	96.5	198.3	100	96.5	98.3
Kelantan	61.5	66.4	64.0	61.7	67.7	64.7
F.T. Labuan	100	100	100	100	100	100
Melaka	100	100	100	100	100	100
N. Sembilan	100	99.8	99.9	100	99.8	99.9
Pulau Pinang	100	99.7	99.9	100	99.7	99.9
Pahang	100	96.0	98.0	100	96.0	98.0
Perak	100	99.2	99.6	100	99.2	99.6
Perlis	100	99.0	99.5	100	99.0	99.5
Sabah	99.8	76.0	87.9	99.8	79.0	89.4
Sarawak	99.8	78.0	94.2	99.8	80.4	94.5
Selangor	100	99.5	99.8	100	99.5	99.8
Terengganu	99.1	92.9	96.0	99.1	92.9	96.0
National Average	**97.2**	**93.0**	**95.5**	**97.2**	**93.5**	**95.7**

Notes:
The percentage of coverage in Kelantan is low because other alternative sources are used although there is accessibility.

Source: Malaysia Water Industry Guide (2017)

Table 4: Non-Revenue Water (NRW) 2015-2016

State	2015				2016			
	System Input Volume	Billed Authorised Consumption	NRW	NRW (%)	System Input Volume	Billed Authorised Consumption	NRW	NRW (%)
	MLD				MLD			
Johor	1,702	1,266	436	**25.6**	1,737	1,286	450	**25.9**
Kedah	1,316	702	614	**46.7**	1,362	725	637	**46.7**
Kelantan	454	231	222	**49.0**	471	238	232	**49.4**
F.T. Labuan	71	49	22	**30.9**	72	50	22	**30.5**
Melaka	481	388	93	**19.3**	500	405	95	**19.0**
N. Sembilan	757	493	264	**34.8**	773	520	253	**32.7**
Pulau Pinang	1,014	813	202	**19.9**	1,054	827	227	**21.5**
Pahang	1,128	532	596	**52.8**	1,111	579	532	**47.9**
Perak	1,260	878	382	**30.3**	1,318	916	402	**30.5**
Perlis	220	96	124	**56.3**	243	96	148	**60.7**
Sabah	1,229	552	677	**55.1**	1,221	586	634	**52.0**
Sarawak	1,268	846	423	**33.3**	1,328	850	479	**36.0**
Selangor	4,675	3,178	1,497	**32.0**	4,807	3,260	1,547	**32.2**
Terengganu	621	428	192	**31.0**	628	440	189	**30.0**
MALAYSIA	**16,195**	**10,452**	**5,743**	**35.5**	**16,625**	**10,779**	**5,846**	**35.2**

Source: Malaysia Water Industry Guide (2017)

Despite efforts to improve management of water supply and its distribution, the rate of non-revenue water (NRW) declined from 35.5% in 2015 to 35.2% in 2016. This is due to the effective enforcement and faster replacement of pipes, as well as efficient of district metering zones to monitor water pressure and detect burst pipes. However, the NRW rate was highest in Perlis at 60.7% and Sabah at 52%.

Table 5: Water Treatment Plants Design Capacity and Production (1981-2016)

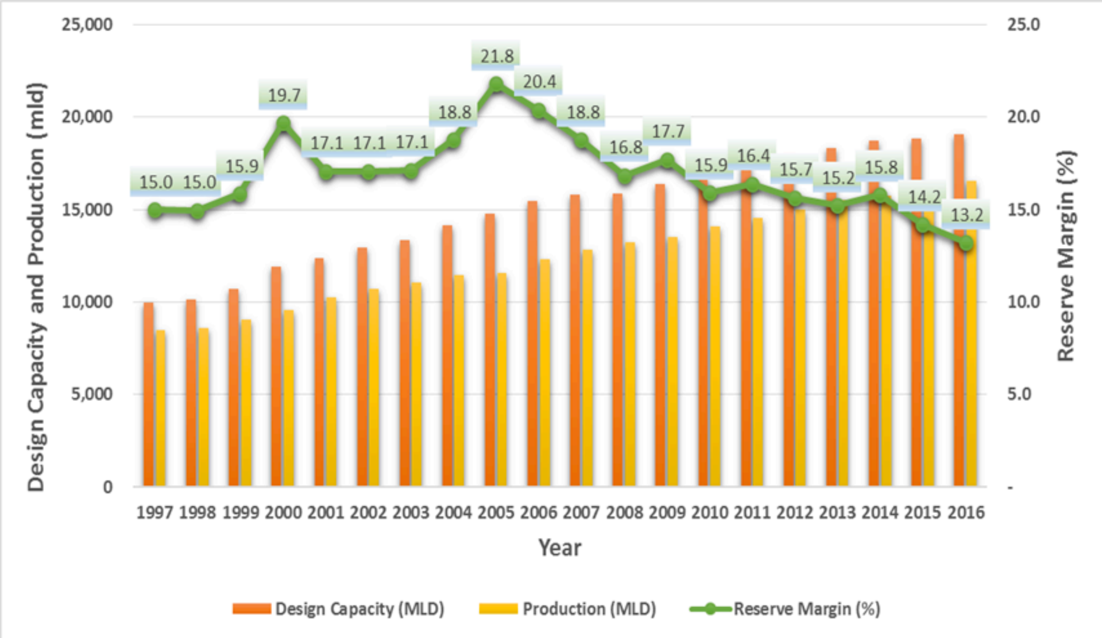


Table 6: Water Treatment Plants Design Capacity and Production 2015-2016

State	2015				2016			
	No. of WTPS	WTPs Design Capacity (MLD)	Production (MLD)	Reserve margin (%)	No. of WTPS	WTPs Design Capacity (MLD)	Production (MLD)	Reserve margin (%)
Johor	44	1,986	1,619	**18.5**	44	1,986	1,661	**16.4**
Kedah	36	1,308	1,315	**0.0**	36	1,308	1,361	**0.0**
Kelantan	35	500	454	**9.2**	35	500	471	**5.8**
F.T. Labuan	6	101	73	**27.6**	6	101	72	**29.2**
Melaka	9	639	519	**18.8**	9	639	510	**20.1**
N. Sembilan	23	994	752	**24.4**	23	1,000	779	**22.1**
Pulau Pinang	9	1,479	1,014	**31.4**	9	1,599	1,054	**34.1**
Pahang	76	1,414	1,129	**20.1**	76	1,414	1,111	**21.4**
Perak	46	1,816	1,289	**29.0**	46	1,846	1,317	**28.7**
Perlis	4	233	220	**5.6**	4	233	230	**1.0**
Sabah	73	1,304	1,229	**5.8**	73	1,304	1,221	**6.4**
Sarawak	93	1,609	1,268	**21.1**	93	1,675	1,328	**20.7**
Selangor	34	4,606	4,675	**0.0**	34	4,606	4,807	**0.0**
Terengganu	12	846	603	**28.7**	12	846	616	**27.2**
MALAYSIA	**500**	**18,835**	**16,159**	**14.2**	**500**	**19,056**	**16,536**	**13.2**

Source: Malaysia Water Industry Guide 2017

Malaysia has built 24 new water treatment plants and an additional 38 plants were upgraded. This has increased its production capacity to 16,536 million litres per day. These initiatives have expanded the coverage of clean and treated water networks and ensured the security of supply.

Overview of Water Demand in Malaysia

Water consumption is divided into domestic and non-domestic. Domestic water use refers to water used for indoor and outdoor household purposes such as drinking, preparing food, bathing, washing clothes and dishes, brushing your teeth, and watering the yard and garden. Non-domestic consumption refers to industrial, commercial, and public uses of water such as shops, offices, schools, and hospitals, among others. The levels of industrial consumption depend on the intended output and resource technology. The industrial consumption is commonly expressed in litres per unit of product or raw material. Table 7 presents the proportion of water consumption. The percentage of domestic consumption increased from 6,378 mld (2015) to 6,495 mld (2016) whereas for non-domestic consumption also increased from 4,074 mld (2015) to 4,242 mld (2016).

Table 7: Total Volume and Proportion of Water Consumption 2015-2016

State	2015					2016				
	Domestic		Non-Domestic		TOTAL	Domestic		Non-Domestic		TOTAL
	MLD	%	MLD	%		MLD	%	MLD	%	
Johor	811	64.1	455[r]	35.9	1,266[r]	773	60.1	513	39.9	1,286
Kedah	511	72.8	191	27.2	702	525	72.4	200	27.6	725
Kelantan	159	68.6	73	31.4	232	163	68.3	76	31.7	239
F.T. Labuan	17	35.2	32	64.8	49	17	34.1	33	65.9	50
Melaka	202	52.0	186	48.0	388	206	50.8	199	49.2	405
N. Sembilan	276	55.9	217	44.1	493	287	55.2	233	44.8	520
Pulau Pinang	483	59.5	329	40.5	812	492	59.5	335	40.5	827
Pahang	309	58.2	223	41.8	532	342	59.0	238	41.0	580
Perak	628	71.5	250	28.5	878	655	71.4	262	28.6	917
Perlis	81	84.2	15	15.8	96	82	85.4	14	14.6	96
Sabah	315	57.1	237	42.9	552	335	57.1	252	42.9	587
Sarawak	478	56.5	368	43.5	846	474	55.7	376	44.3	850
Selangor	1,862	58.6	1,316	41.4	3,178	1,883	58.5	1,336	41.5	3,219
Terengganu	246	57.5	182	42.5	428	264	60.0	176	40.0	440
MALAYSIA	**6,378**	**61.0**	**4,074**	**38.9**	**10,452**	**6,495**	**60.5**	**4,242**	**39.5**	**10,737**

Source: Malaysia Water Industry Guide 2017

Based on National Water Resource Study 2000-2050 the water demand for domestic consumer will be increased from 2000 till 2050, respectively 2,029 million m^3 to 5,904 million m^3. The total volume also rises from 10,833 million m^3 to 17,675 million m^3 (Table 8).

Table 8: Water Demand for Peninsular Malaysia (Million m^3/yr)

Demand*	1998	2000	2010	2020	2030	2040	2050
Domestic	1,833	2,029	2,987	3,862	4,606	5,251	5,904
Industry	1,260	1,454	2,592	3,561	4,330	5,016	5,639
Both	3,093	3,483	5,578	7,423	8,936	10,267	11,543
Irrigation	7,350	7,350	6,517	6,517	6,517	6,132	6,132
Total	**10,443**	**10,833**	**12,095**	**13,940**	**15,068**	**16,399**	**17,675**

*Include losses

Source: National Water Resource Study 2000-2050

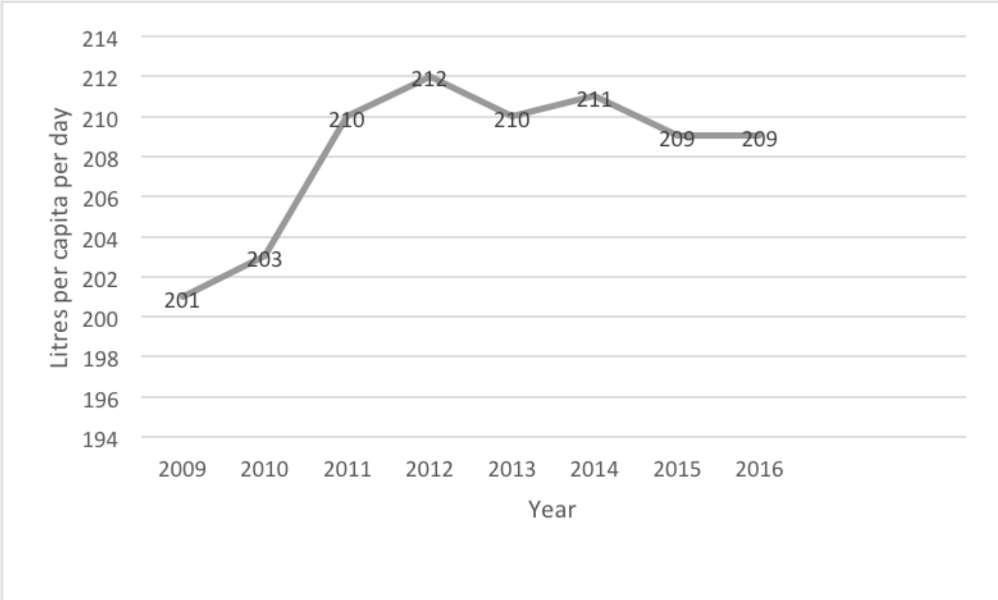


Figure 2: Domestic Consumption Per Capita Per Day in Malaysia (2009 - 2016)
Source: Malaysia Water Industry Guide 2017

The average domestic water consumption (DWC) is 285 litres per capita per day compared to the average of 36 Asia countries at appropriately 165 litres and a United Nation (UN) guideline of 160 litres per capita per day.

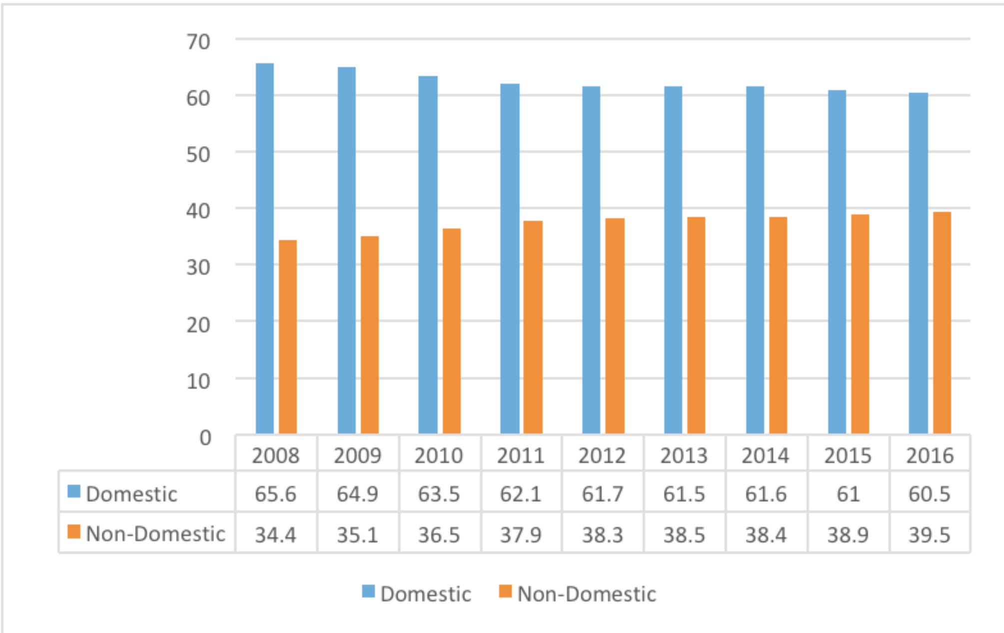


Figure 3: Total Volume of Water Consumption 2008 - 2016
Source: Malaysia Water Industry Guide 2017

Determinants of Water Demand

Numerous factors impact on the demand for water. The most influential factors are climatic such as rainfall, temperature and evaporation rates and population related such as population growth, population density, water price as well as socio demographics (Slavíková et al., 2012; Duarte et al., 2013). Household characteristics

(Syme et al., 2004), water availability and conservation (Davies et al., 2014), and pricing and policies (Jorgensen et al., 2009) are also major determinants of water usage.

Syme et al. (2004) found that outdoor water consumption and use behaviour concentrated in watering gardens, cleaning and swimming pool, and that these practices were shaped by climate, income, lifestyle and water conservation practices. Regarding indoor use, it was determined by household appliances and water conservation practices (Gregory and Di Leo, 2003).

Different cities use water differently. Indian and Palestinian cities modify their practices based on water supply capacity (Andey and Kelkar, 2009). In northern Nigeria, precipitation brought about by seasonal changes determine consumption practices (Nyong and Kanaroglou, 2001). In Hong Kong and Beijing, the national gross domestic product (GDP) is highly related to increases in the rate of base water use (Zhang et al., 2013). In California, water price (WP), water appliances and water-saving subsidies are the main factors associated with water consumption (Renwick and Archibald, 1998).

In total, there are 15 major determinants of water demand consisting of climatic factors (two variables), water tariffs, socioeconomic factors (seven variables), water appliances (two variables), and water supply and conservation factors (three variables).

Sustainable Development of Water Resources

The world is facing unprecedented challenges in water resources management. Water is essential for life because humans cannot live without water for more than several days. In Malaysia, the government promotes holistic development by implementing proactive policies and strategies at different levels starting from the 7th Malaysia Plan onwards.

Barrier (2004) revealed growth is negatively affected by the government's appropriation of output to supply water but positively influenced by the contribution of increased water use to capital productivity, leading to an inverted U relationship between economic growth and the rate of water utilisation. The majority of economies continue to use fresh water to support growth, while others suffering from high levels of water scarcity could see their economic growth suffer due to the inability to sustain industry.

Given recent climatic and environmental trends, the world is anticipating a significant rise in water scarcity. This is confounded further by the ongoing rise in global production and consumerism (Vörösmarty et al., 2000).

It is necessary to model the relationship between water use and economic growth by determining the economic value of water. Despite changing water capacity leaning towards the privatisation of water, water continues to be perceived as a government-provided non-excludable good subject to congestion.
Barro (1990) and Barro and Sala-I-Martin (1992) argued that modelling the influence of water utilisation on economic growth helps form a growth model that includes

publicly provided goods that are subject to congestion as a productive input for private producers in an economy.

In China, Fang et al. (2006) investigated the relationship between water scarcity and growth by examining the impact of intersectoral and interregional water allocations on growth.

Hossein et al. (2012) presented evidence supporting the hypothesised inverted U relationship between economic growth and the rate of water use across countries. The result suggests that current rates of freshwater utilisation in the vast majority of countries are not yet constraining economic growth.

These studies underscore the importance of water for economic growth. In other words, development cannot be continued without water. Hence, the water resource needs to be developed and managed sustainably to ensure the social, economic and environmental development for the current and future generations. As a result, Sustainable Development Indicators (SDI) for water have been introduced to monitor the water sustainability.

Population and Water in Malaysia

Malaysia's current population is 32.04 million. An increase in the population leads to higher demand for water supply in residential, industrial and agriculture sectors.

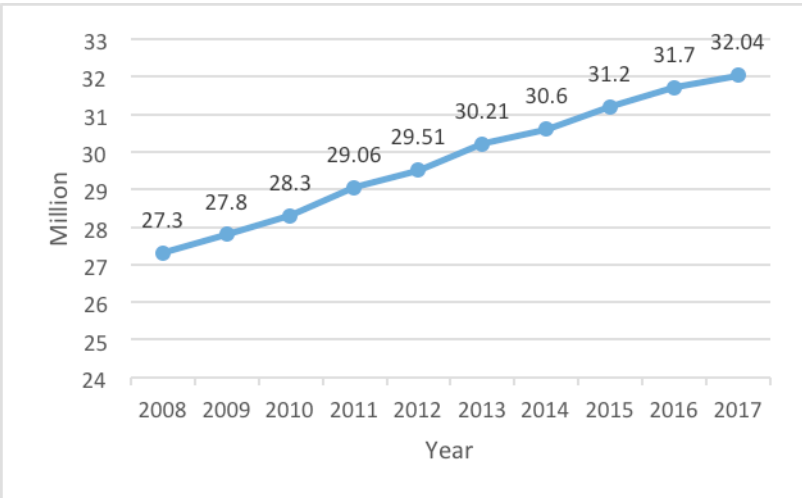


Figure 4: Population Growth in Malaysia (2008 - 2017)
Source: Department of Statistic Malaysia

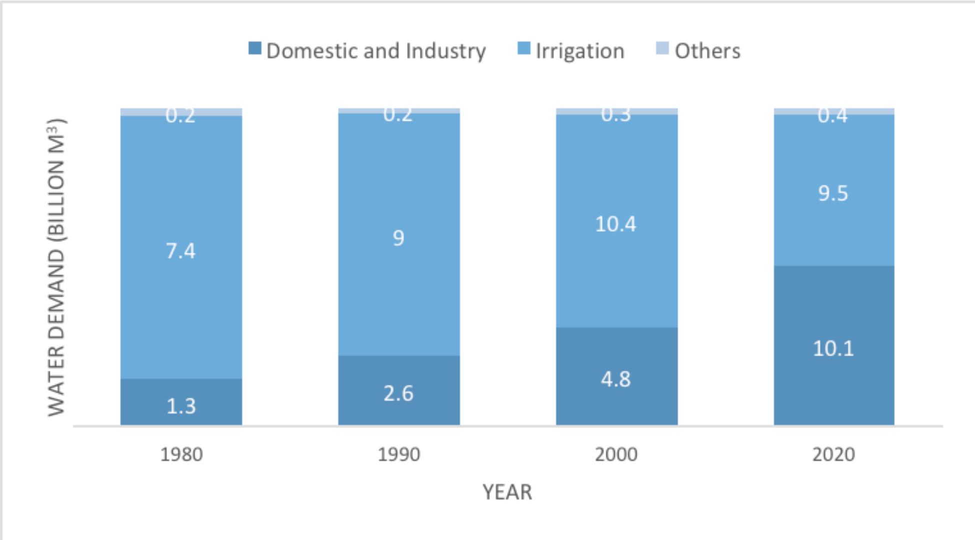


Figure 5: Water Demand for Different Sector in Malaysia (1980-2020)
Source: EPU (Economic Planning Unit) 2006. The Ninth Malaysian Plan (2006-2010). Prime Minister's Department, Putrajaya, Kuala Lumpur, Malaysia

Figure 5 shows the demand for water in different sectors in Malaysia from 1980 to 2020. The total demand for water in the country was 8.9 billion m^3 in 1980. Usage of water for irrigation accounted for 83% of the total water usage in 1980. The demand for water increased to 11.8 billion m3 in 1990 for agricultural, industrial and domestic purposes. It was found that agricultural sector constituted the highest portion (76%) of the total water usage in 1990. The water distributed in the agricultural sector was used for irrigation of eight large paddy granary schemes and 924 smaller schemes, which combined a total area of 340,000 hectares 10. Water demand had steadily increased to 15.5 billion m^3 in 2000. As usual, the agricultural sector comprised the greatest portion (67%) of the total water usage while the demand for water in the industrial and domestic sector increased nearly two-fold during the 2000s.

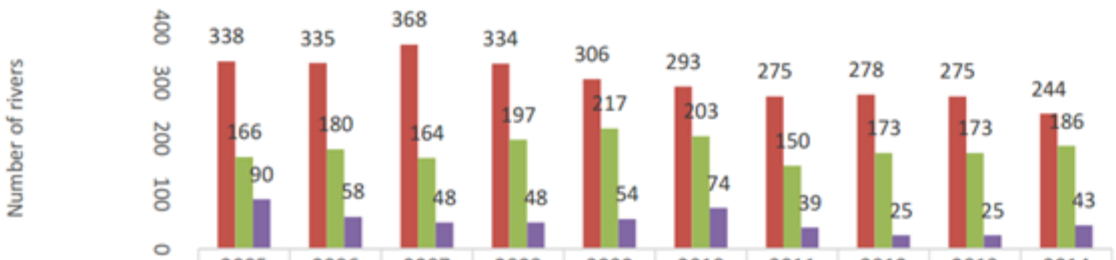
The industrial and domestic sectors use water predominantly for hydropower, navigation and recreational activities. Between 1980 and 2000, Malaysian dedicated most of its water resources to the agriculture sector. The domestic and industrial sector also recorded increased water demand of approximately 12% annually over the same period. This was spurred by a growing population and economic growth. It is anticipated that Malaysia's demand for water would reach 20 billion m^3 by the year 2020. A national agenda to industrialise and boost economic growth means that the industrial demand for water is projected to constitute nearly 51% of the total water demand by 2020.
In conclusion, as the population grows, the demand for water mounts and pressure on finite water resources intensifies. Climate change, which is also closely tied to population growth, will also lead to greater pressures on the availability of water resources.

Impact on the Environment

Population Impact on Future Water Quality

More people means more demand for water. It also entails the possibility of greater waste and pollution which threaten the water supply further. Malaysia suffers from high levels of pollution which have affected its water resources significantly.

As reported by Department of Environment in Figure 5, of state of the rivers of473 rivers monitored for water quality, 244 (52%) were clean, 186 (39%) were slightly contaminated, and 43 (9%) were infected.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Clean	338	335	368	334	306	293	275	278	275	244
Slightly polluted	166	180	164	197	217	203	150	173	173	186
polluted	90	58	48	48	54	74	39	25	25	43

Year

Figure 6: River Water Quality Trend in Malaysia

Issues and Challenges of Water Resources in Malaysia

Malaysia is a developing country with a growing population, particularly in urban centres due to rural-urban migration and growing urbanisation. It has strained the government's ability to meet infrastructure and service needs and provide the environmental conditions required for better living. This includes water treatment facilities overwhelmed by the population which has direct and immediate consequences for health and the environment.

The increased demand for increasingly limited water supply has created competition for water resources. The obvious answer to the problem is to build more dams which are costly financially and environmentally. Furthermore, the practicable limit of surface water resources development has been reached in some regions of high demand, and it has become necessary to consider inter-basin and interstate surface water transfer schemes.

Floods are natural phenomena that can be exacerbated by poor development policies and practices. The high rate of sedimentation in the rivers has adversely affected their drainage capacity, leading to more frequent floods in downstream areas and more intense flooding. Flash floods in urban areas are becoming more frequent as a result of the runoff from industries and residential areas.

In Malaysia, an estimated 29 000 km^2 or 9% percent of the total land area is flood-prone, affecting some 12% of the population. The average annual flood damage was estimated at RM100 million in 1980. This figure is significantly higher nowadays due to the urban sprawl and development.

Floods cannot be controlled effectively. Nevertheless, mitigation measures can be put in place to reduce its impact and cost financially and environmentally. Besides the construction of dams and reservoirs and the improvement of river systems, measures to increase infiltration and to store the excess water in small ponds and retention basins are being promoted. The Department of Irrigation and Drainage is leading these efforts. Public utilities such as water supply, sewerage, and urban drainage and flood mitigation are also helpful.

The main determinants of water pollution are domestic and industrial sewage, effluent from palm oil mills, rubber factories and animal husbandry. Mining operations, housing and road development, logging and clearing of forest are major causes of high concentrations of suspended sediments in the rivers. In several urban and industrial areas, organic pollution of water has resulted in environmental problems and adversely affected aquatic life. In addition to organic wastes, rivers remain a convenient means of solid waste disposal. A major portion of household refuse which is not collected, burnt or buried finds its way into drains and rivers. In the Klang Valley, an estimated 80 tonnes of waste ends up in the river system every day. River water quality and pollution control need to be addressed urgently since 98% of the total water originates from rivers. Almost all of the investments in water-related infrastructure depend on reasonable river water quality.

Malaysians are highly inefficient in their use of water. Despite its significant agriculture, it has a rather inefficient open irrigation system which takes advantage of flooding. The cost of irrigating farmland is relatively cheap leading people to be careless in their use of water. There is also a high proportion of unaccounted-for water in urban water supply systems, as one-quarter to one-third of the domestic and industrial water is lost before it reaches the consumers. This is partly due to poor infrastructure leading to leaks in addition to illegal activities. Such a state has led the authorities to focus on improving water efficiency more so than securing additional water resources.

Malaysia’s growth means that standards of living have improved. Water shortages are improving environmental and conservation awareness. Nevertheless, higher standards of living mean that the demand continues to place growing pressure on the water supply, despite awareness. This challenge is being addressed through a focus on improving efficiency in water processing and consumption.

According to Chan (2003), there are major issues that must be addressed to ensure sustainability of water resources for now and in the future. In Malaysia, the water management system depends on the water supply management approach to cater for demand. This approach is not sustainable due to the fact that will exceed the water supply in the long run. It means that when demand increases, water supplied will rise as well, and more infrastructure like dams, water treatment plants and pipes for water supply distribution should be built. The comprehensive approach is required to ensure the sustainable water resource and integrated supply and demand-side management needed. Also, to change the consumptive behaviour of Malaysians to use water wisely.

Rates of water wastage are very high compared to other countries in the domestic, industrial and agriculture sectors. As reported by United Nations, Malaysia’s national average for per capita water use per day was 287 litres in 2001 compared with 165 litres per capita water use per day in the average of Asian countries. Moreover, rates of NRW are too high, approximately with a national average of 37.70%. If this could be reduced, Malaysia would have sufficient water supply with no need to build new dams.

Additionally, water catchments have been gazetted and protected by the government. If not, it will be exposed to development which is affecting the environment and water resources. Changing climates and weather also affect the water resources. For instance, in 1997/98, there Malaysia suffered a water crisis caused by El Nino. This situation should be taken into account in planning water resources development.

Malaysia has the lowest water prices in the world. Due to this low price, customers over-use water and are not encouraged to take water conservation measures. The process of reviewing the water rates should be transparent and involve professional and public participation to achieve water sustainability. About 68.2% of total water consumption is for agriculture purpose. However, irrigation efficiency is 50% at best in the larger irrigation schemes and less than 40% in the smaller ones. The government needs to encourage the water recycling and sustainable agriculture practices. Finally, due to serious problems of water pollution, the cost of treating polluted waters is very high and negatively impacts on the sustainability of water resources.

Conclusions and Policy Implications

Malaysia is rich in water resources. Its increasing population means higher water demand. Climate change also contributes to water shortage, particularly in the dry season. Currently, the water providers have been regulated by SPAN which is one regulatory body, uniform legislation, uniform legislation and rules, uniform tariff-setting principles and procedures, standard key performance indicators (KPIs), standard operating procedures, and standard product certification procedures will be implemented. Additionally, the framework on water services reform includes the federal government, state governments, the National Water Resource Council (NWRC), the National Water Services Commission and the Water Asset Management Company (WAMCo).

Moreover, the aims of restructuring the framework of water industry services are to ensure a high level of efficiency of services and operation; to upgrade water quality and ensure continuous and sufficient supply; to reduce non-revenue water (NRW); to relieve the state water operator’s financial burden; and to develop a progressive and effective water services industry. In other words, it is to promote sustainable and holistic water supplies and sewerage services in the best interest of consumers and the environment as well as addressing funding requirements for infrastructure development.

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In Support of Greening the Economy: How to Enhance TVET's Contribution to the Development of Generic Green Skills

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Abstract
Technical and vocational education and training (TVET) plays a significant role in supporting green economic restructuring and tackling environmental problems through skills development. This paper outlines current theories and some practices related to pedagogy for education for sustainable development (ESD) that can enhance TVET's contribution to generic green skills development. It reviews the pedagogical approaches and strategies commonly used in ESD curriculum to develop students' key sustainability competencies. Following on from this, the paper reports on the results of a pilot study where the researcher observed classes in a TVET institution and interviewed the staffs involved in teaching a generic green module. It also elaborated an ESD pedagogical model developed based on the finding of literature review and the pilot. The study revealed a significant gap between pedagogical approaches put forward in literature and ESD pedagogical practices within the context of TVET. In particular, lecture-based pedagogy observed during the study and the less locally relevant learning content cannot stimulate students' participation and learning motivation. Interviews also identified the challenge for teaching staffs in terms of transforming their role from a teacher-centered approach to the role of facilitator. This pilot study suggested, problem-oriented and project-organized pedagogical framework that includes real-world learning opportunities has potential to enhance the implementation of generic green modules to facilitate the development of students' generic green skills.

Keywords: Green skills, Generic green skills, TVET, ESD pedagogy, real-world problem solving

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Introduction

Challenges faced by humanity have led to the formulation of the concept of sustainable development. As a result, government put in place different measures to insure green restructuring of economy. Therefore, the requirement of innovation and other changes related to green restructuring has an important impact on the labour market restructuring and green skills development.

Since early 2000s, the contributions of **Technical and Vocational Education and Training (TVET)** to sustainable development have been widely acknowledged. UNESCO (2006) identified the significant role of TVET in facilitating green economic growth and its contribution to a sustainable future. Publications on the topic also revealed that TVET has a crucial role to play in **the world of work**, which prepares workforces to consider environmental and sustainability aspects in their professional practice and embrace green technology (e.g. Maclean, 2005; Siriwardene & Qureshi, 2009; Mertineit, 2013; Pavlova, 2015; Baryono, 2017). United Nations (2015) also regarded TVET as a means to achieving sustainability since **TVET almost underpins all the Sustainable Development Goals (SDGs)**.

Furthermore, since 2010, the understanding of TVET's contribution to sustainable development has been broadened, where TVET has started to re-orientate curriculum towards the inclusion of **Education for Sustainable Development (ESD)**. Although positive processes of greening TVET have been observed worldwide, many aspects of its effective implementation were still under-researched (Pavlova, 2016). First, the curriculum related to sustainability has been critiqued as more than a lofty theory, while ESD education requires action "on the ground" that provide opportunities for students to put sustainability principles into practice. However, over the last decade, sustainability education was positioned as "add-on" to disciplinary curricula or campus-based project learning (Brundiers & Wiek, 2011), and limited study has been done to examine how real-world learning opportunities could be integrated and contribute to sustainability education especially within TVET context. Additionally, traditional teaching methods such as lectures, may hardly equip students with required competences to make transition from the classroom to profession (Steinemann, 2003). Moreover, TVET pedagogy has been criticized due to its fails to prepare students with green skills as it utilized relatively uncritical response to industry demands, which tends to focus on fueling productivity, efficiency and economic growth through skills training but ignore the unintended environmental and social consequences (Anderson, 2009; Arenas & Londono, 2013, Bedi and Germein, 2016).

In Hong Kong, the processes and structures to facilitate skills learning through training have been put in place by government and businesses. Training Providers in Hong Kong such as Hong Kong Productivity Council (HKPC), Hong Kong Vocational Training Council (VTC) have provided broad opportunities for skills learning through different training programs (Pavlova, 2016). Green skills have been included in these training programs to some extent since there is a need for developing green economy and a more sustainable future. One of the approaches for introducing green skills in these programs is through developing new learning module that includes green knowledge and reflection on green practice needed for greening economy and society. However, the effectiveness of implementing these learning modules and equipping students with green skills/ competences[1] has not been well examined. There is hardly any research has been done that focuses on the classroom practices during these modules delivery.

Therefore, this study intended to develop the theories and practice of ESD pedagogical innovation within TVET. It developed an ESD pedagogical model based on the finding of the literature review and a pilot study conducted in a TVET institution in Hong Kong, which aimed to contribute to minimize the gap between pedagogical theory and practice in greening TVET curriculum and enhance TVET's contribution to the generic green skills development.

1 Literature Review: Conceptual Framework

This section clarifies the concepts relevant to this study and identifies the suggested ESD pedagogical approaches and strategies. First, it reviews literature on the understanding of ESD, and conceptualizes the concept of ESD pedagogy based on the clarification of ESD and ESD learning processes. Second, it reviews the definitions of green skills to demonstrate the relationship between sustainability competences and green skills, and lists the classification of generic green skills. Last, it reviews the suggested approaches and strategies related to ESD pedagogy to shed light on the formulation of an ESD pedagogical framework for this study.

1.1 The conceptualization of ESD pedagogy

Commonly, ESD is regarded as a particular way for linking education and sustainable development, although it is described and conceptualized variously regarding to different interpretation of sustainable development and educational ideologies (Corney and Reid, 2007). For instance, UN DESD regards ESD as a sustainable development program, which emphasizes that

> *"ESD, must consider the **three spheres of sustainability – environment, society (including culture), and economy**. Because ESD addresses the local contexts of these three spheres, it will take many forms around the world* (UNESCO, 2005, p28)

The World Conference on Education for Sustainable Development (2009) defined ESD as "**an approach to teaching and learning** based on the ideals and principles that underlie sustainability".

As this study is to explore the ways that how ESD pedagogy could be applied and innovated to facilitate the development of generic green skills within TVET, it defines ESD as a way to link education and sustainable development, which put learning in the center of efforts and initiatives to foster sustainability.

Additionally, there is no specific definition regarding to ESD pedagogy in the literature, and the literature on specific pedagogies for ESD is limited as well

[1] Green skills and competences was used interchanges in this study, meaning that skills are interpreted in a broad sense and include skills, knowledge and attitude that facilitate people to understand the need for a sustainable future and behave accordingly.

(Summers et al., 2005; Corney and Reid, 2007). The ESD Sourcebook (Learning & Training Tools NO.4, 2012) identifies ESD pedagogy as

> *"... often* ***place-based or problem/issue-based****. ESD pedagogies* ***encourage critical thinking, social critique, and analyses of local contexts****. They* ***involve discussion, analysis and application of values****. ESD pedagogies often* ***draw upon the arts*** *using drama, play, music, design, and drawing to* ***stimulate creativity and imagine alternative futures****".* (UNESCO, 2012, p.15)

Similarly, a research that synthesizes the studies carried out in 18 countries to identify the contribution of ESD to quality education also reveals that **ESD pedagogies promote cooperation and collaboration, issues investigation, real-work problem solving from multiple perspectives and equity in the classroom by meeting all student needs**. It further indicates that although many ESD pedagogies has been used in practices within different disciplinary traditions for years, they are now implemented in **interdisciplinary contexts** and applied to **address sustainability issues**. These ESD pedagogies do more on developing learning of skills, perspective and values required for sustainable societies instead of facilitating learning of knowledge (Laurie, R., Nonoyama-Tarumi, Y., Mckeown, R., & Hopkins, C., 2016).
It can be seen that these identified characteristics of ESD pedagogy are consistent with the characteristics and key learning processes of ESD reviewed below.

- *Interdisciplinary and holistic*
- *Values-driven*
- *Critical thinking and problem solving*
- *Multi-method*
- *Participatory decision-making*
- *Applicability*
- *Locally relevant*
  Source: Implementation Scheme of United Nations decade of education for sustainable development (DESD), UNESCO, 2005, pp. 18.

Additionally, the **key ESD Learning processes** that underpin ESD frameworks and practices were reviewed by Tilbury (2011) as

- *Processes of* ***collaboration and dialogue*** *(including multi-stakeholder and intercultural dialogue);*
- *Processes which engage the* ***'whole system'****;*
- *Processes which* ***stimulate innovation*** *within curricula as well as through teaching and learning experiences; and,*
- *Processes of* ***active and participatory learning****.*
  Source: Tilbury, 2011, p. 31.

Therefore, ESD pedagogy can be understood as the **teaching and learning methods and strategies** that facilitate **the implementation of the key learning processes of ESD** in order to equip students with **sustainability competences**. This study use the concept of "ESD pedagogy" to emphasize the importance of transforming the key learning processes of education for sustainable development (ESD) into pedagogical innovation for TVET.

1.2 Conceptualization of Green Skills and the classification of Generic Green Skills

"Green skills" is a relatively new research area with the first publications appearing after 2009. There is a lack of consistency in interpreting green skills in literature (Pavlova, 2016). As this study aims to explore how ESD pedagogy could be applied and innovated to facilitate generic green skills[2] development within TVET, the nature of green skills and its classification is discussed and conceptualized below.
Green skills are interpreted as

> "***Technical skills, knowledge, values and attitudes*** *needed in the workforce to develop and support* ***sustainable social, economic and environmental outcomes in business, industry and the community***" (NCVER, 2013).

Another definition provided by Cedefop (2014) defined green skills as

> *"Abilities needed to live in, develop and support a society which aims to* ***reduce the negative impact of human activity on the environment****".*

The primary definition of green skills identified above reveals, firstly, green skills are proposed based on the concept of sustainability, which highlight the significance of developing sustainable society, economy and environment, though green skills tend to place more emphasis on the sphere of environment. In addition, green skills are regarded as the skills for sustainability in some literatures. For instance, skills for sustainability is considered to be the same as green skills in the policy paper of "The Australian Green Skills Agreement" (Council of Australian Governments, 2012). Acedo (2014) also indicates the relationship between ESD and green skills as "***ESD is at the core of green skills****… There can be no sustainable development without education and without* ***appropriate green skills for employability***" (p. 137-139). Secondly, it was emphasized that, green skills should play a major role in the greening of business, industry and community, which raise the challenges for TVET to develop workforce to support greener economy and society. Accordingly, green skills could be regarded as **the sustainability competences that especially require for green growth** (including environmental, social and economic aspects) within TVET context.

Moreover, the CEDEFOP (2010) study articulates what are specific green skills, generic green skills and the necessity of topping-up existing skills. Regarding to the distinction between generic green skills and specific green skills, it is widely accepted in the literature that, the former are **generic/ key/ core competences needed in almost any occupation**, and the latter are **task-oriented competencies required for a specific occupation**(e.g. Rychen and Salganik, 2003; European Commission, 2007; Pellegrino and Hilton, 2012; Pavlova, 2016). However, there is a terminological debate and ambiguity, which associate the term "competencies" with skills, abilities, capabilities, capacities, qualification and other concepts (Baartman et al. 2007; Wiek, Withycombe & Redman, 2011; Pavlova, 2016). This study employs the definition that emphasizes competency as

[2] Generic Green Skills is one type of green skills, see literature review below.

> *"**knowledge, skills and attitudes** that enable successful task performance and problem solving with respect to real-world sustainability problems, challenges, and opportunities"* (Dale and Newman 2005; Rowe 2007; Barth et al. 2007, cited in Wiek, Withycombe & Redman, 2011, p. 204).

Therefore, green skills could be understood as the knowledge, skills and attitudes (including values) required for developing and supporting the green growth. They were categorized as generic green skills and specific green skills. Specific green skills includes the specific competences required for green industries and the topping-up existing competencies required in all industries. Generic green skills are the "general" competencies required in almost any occupation in order to facilitate the future workforce to understand the green growth issues and increase their environmental awareness.

Specifically, Pavlova (2015) further classifies the identified generic green skills into four categories, namely cognitive competencies, interpersonal skills, intrapersonal competencies and technological skills, based on two approaches (OECD and ILO, 2011; combined and Percapita Report, 2010).

Cognitive Competencies

- Environmental awareness and a willingness to learn about sustainable development
- Systems and risk analysis skills to assess, interpret and understand both the need for change and the measures required
- Innovation skills to identify opportunities and create new strategies to respond to green challenges

Interpersonal Skills

- Strategic and leadership skills to enable policymakers and business executives to set the right incentives and create conditions conducive to cleaner production, cleaner transportation, etc.
- Coordination, management and business skills to facilitate holistic and interdisciplinary approaches that encompass economic, social and ecological objectives
- Communication and negotiation skills to discuss conflicting interests in complex contexts
- Marketing skills to promote greener products and services
- Networking, IT and language skills to enable participation in global markets
- Consulting skills to advise consumers about green solutions and to spread the use of green technologies

Intrapersonal Competencies

- Adaptability and transferable skills to enable workers to learn and apply the new technologies and processes required to green their jobs
- Entrepreneurial skills to seize the opportunities of low-carbon technologies

Technological Skills

- Quantification and monitoring (waste, energy, water)
- Management systems (waste, energy, water)
- Procurement and selection
- Material use and impact quantification
- Impact and use minimization
- Impact assessment
- Risk management

Source: Pavlova, M. (2017) Green Skills as the Agenda for the Competence Movement in Vocational and Professional Education. (pp. 936-937).

1.3 The Identified ESD Pedagogical Approaches

Teaching and learning through **solving actual, real-world sustainability problem** has been suggested as an effective approach to address sustainability competencies in literature (Rowe, 2007, Brundiers et al., 2010, Remington-Doucette, et al. 2012). Most of the ESD pedagogical framework that incorporate real-world problem solving opportunities are developed based on the approach of **problem-based learning (PBL)**, **project-based learning (PjBL)** or **the integration of PBL and PjBL**(e.g. Brundiers, Wiek & Redman, 2009). Thus, the review below focused on elaborating the theory and practice related to PBL, PjBL and the integrated model of PBL and PjBL.

1.3.1 Problem-based learning (PBL)

Problem-based learning (PBL) is widely identified as an effective approach for ESD as it focuses on complex interdisciplinary problems, which provides students the opportunity to gain experience in addressing complex problem that they may face in future professional careers (Steinemann, 2003). It encourages students to work in a team and integrate theory with practice to find viable solution options for the problem, which is assumed as the purpose of PBL approach to professional education (Savery, 2006).

The foundations of Problem-Based Learning are firmly laid on the work of many researchers such as Dewey, Piaget, Bruner and Gagne. It incorporates the objectives of

- *The development of* ***problem solving ability****;*
- *The development of* ***self-directed learning ability****;*
- *The integrated structuring of learning within the context of the* ***graduate's practice****; and*
- *The encouragement of* ***motivation for learning****.*

1.3.2 Project-based learning (PjBL)

PjBL is a form of situated learning that based on constructivism theory. It indicated that students gain a deeper understanding of learning material when they actively construct their understanding by working with and using ideas in real-world contexts. (Krajcik & Shin, 2014). PjBL, which interweaves knowledge application and project practice, can help students to consolidate and broaden their understandings (Tempelman & Pilot, 2011), and provides opportunity for students to develop the communication, problem-solving and team-working skills which are needed in their future careers (Elshobagy & Schönwetter, 2002). Furthermore, when students perceived that they are developing the professional skills needed for their future careers, their **learning motivation will be enhanced** (Fang, 2012). This kind of motivation can be sustained through meaningful, real-world problem and projects (Bell, 2010)

Additionally, Pavlova (2015) suggested that, PjBL that helps students to understand ethics and the ways issues can be addressed should play a central role in pedagogical approaches to ESD. Similarly, a pan-European study, which compared sustainability subjects in technology universities, found that the most effective pedagogy for students to learn about sustainable development is a community-based project with collaboration of multiple learners as well as use of a constructive learning pedagogy (Jollands & Parthasarathy, 2013).

However, there is no one accepted definition and model of PjBL. Buck Institute for Education (BIE) as a research and development organization that specialized in doing research on project based instruction, has done a lot of work on effective approach of PjBL. This study intends to using the **'BIE Standards-Focused'** PjBL model (Markham, 2003) as the foundation for further developing ESD pedagogical framework. This standards-based PjBL model was formulated to be accessible and well-structured, which clearly specified six steps that can help tutors or students to plan an effective project, including

- Develop a project idea
- Decide the scope of the project
- Select Standards
- Incorporate simultaneous outcomes
- Work from project design criteria
- Create the optimal learning environment

1.3.3 The Integrative model of PBL and PjBL

ESD has increasingly focused on integrating problem- and project-based approach to create more real-world learning opportunities for students to better understand and address sustainability challenges (Wiek et at., 2013; Brundiers and Wiek, 2013; Kricsfalusy, George and Reed, 2016).

Brundiers and Wiek (2013) explained the aims for combining PjBL and PBL as, first the combination of PBL and PjBL can avoid both the risk of "***getting caught in the knowledge-first trap by endlessly analyzing problems***" and "***jumping prematurely to solutions without sufficient problem framing and analysis***" (p. 1728). Second, it can **expand the engagement structure of PBL through involving stakeholders** in a collaborative learning and critical reflection process instead of only involving stakeholders that act as consultor (Brundiers and Wiek, p. 1728).

Accordingly, at least three approaches that focus on the integration of PBL and PjBL can be identified in the literature.

- **Problem- and Project-Based Learning (PPBL) approach**

PPBL approach is developed based on constructivist and experiential learning, which especially incorporates the approaches of PBL and PjBL (Wiek et al. 2013). It adopts the learning process of **problem inquiry as in PBL** in order to develop solution options for problem solving through **group project**. In these settings, learning shifts from passive to active, wherein students investigate a real-world problem and work on solution options by engaging in small-group work (Brundiers and Wiek, 2013).

In addition, Brundiers et al. (2010) initially proposed the ASU-SOS “functional and progressive” PPBL model for building sustainability competence through effectively and structurally integrating real-world learning opportunities into curriculum.

- **Problem Oriented Project-Based Learning (POPBL) approach**

In addition, another similar approach proposed to address ESD was identified as Problem Oriented Project-Based Learning (POPBL). Yasin & Rahman (2011) indicates,

> *“POPBL has to start with **the analysis of a research problem** followed by **the design of the project** to solve the problem through **the implementation of the activity planned** in order to solve the problem under study”* (p. 3).

Four main phases in POPBL approach was suggested as:

I. Group Formation
II. Problem formulation
III. Design and data collection (project implementation) and
IV. Data analysis and report writing.

(Yasin & Rahman, 2011, p.3)

- **Problem-Based and Project-Organized Model (Aalborg Model)**

Aalborg Model (Kjarsdam and Enemark, 1994, see Figure 3) is another integrative approach targeted at problem solving through project work. It is a combination of problem-based (meta-concept) and project-organized approach, and formulated as problem-orientation, project work, interdisciplinary, participant directed-learning, exemplary principle and teamwork (Kolmos, Fink and Krogh, 2006).

All the learning activities in this model are finally centered in the process of problem solving, where the learning process are begin with problem analysis and ended in the project work (report/documentation). Aalborg Model has been used in Aalborg University crossing all educational programs, including the sustainability programs such as Engineering Science and Sustainability (Holgaard, 2016).

In summary, PBL and PjBL are combined in an integrated way to provide student with real world problem solving opportunities in order to foster their sustainability competences. The project work within these ESD approaches/ models mainly plays a role in offering an opportunity for students to address a real world problem and create change in some way, while the problem-oriented/based learning process plays role in facilitating the learning through problem formulation and exploration. In addition, all of these integrative approaches/models have emphasized the importance of interdisciplinary learning, self-directed learning, community involvement and real world problem solving. Nevertheless, they still have some difference. First, PPBL approach, which emphasis outside-classroom settings as a learning laboratory, tends to pay more attention on creating real-world learning opportunities for students throughout different processes. Second, POPBL approach place more emphasis on the characteristic of problem-oriented as it argued problem formulation is the large part of the learning process. Third, the Aalborg PBL model (problem-based and project-organized learning) is originated from PBL approach, which highlights the principle that all the learning activities should be organized centering in problem solving.

Although these models were developed and used mainly in higher education (Bachelor and Master Level) and were not specified to TVET context, they provides important theoretical foundation for the development of ESD pedagogical model for TVET.

1.4 The Identified ESD Pedagogical Strategies

Considering on essential role of pedagogical strategies for effective classroom practices, this section reviews the identified ESD pedagogical strategies used or proposed to be used in ESD related courses to identify their main features.

Tilbury (2011) reviewed approximately 200 articles to understand the processes and learning for ESD in the Phase II of the DESD. The list of ESD pedagogical strategies (**Table 1**, see below) summarized in the Phase II report was adapted from a study (Cotton and Winter, 2010). It revealed the common ESD pedagogical strategies adopted in higher education.

In addition, Lozano et al. (2017) reviewed the pedagogical strategies that can be used in delivering sustainability-oriented course and proposed twelve pedagogical strategies selected from those that have well-cited references in ESD literature or are known to be broadly used. These pedagogical strategies are non-exclusive, with some overlap in techniques among them and a clear potential to use two or more of these educational strategies synergistically.

In summary, all these identified and classified pedagogies strategies could be flexibly used in different ESD learning context. The application of these ESD pedagogical strategies within different ESD learning context should be considered holistically, such as students' characteristics and their previous learning experience about sustainability, the learning objectives set for a specific lesson as well as the learning resources and space provided for sustainability education.

Pedagogical strategies	***Learning process involved***
Reflexive accounts	Considering their own position in relation to new knowledge about sustainability can help students understand how individual actions contribute to sustainability. This pedagogical approach provides opportunities for learners to reflect on personal roles, attitudes and responsibilities in relation to a range of sustainability issues.
Critical reading and writing	Reading and writing are seen by tutors as important social practices and the key to progressing sustainability and literacy. Learners can gain from deconstructing discourses to identify the possible motivation of the author. They may also be able to envisage alternative futures, and write a contrasting account based on differing perspectives.
Problem-based learning	Problem-based learning is an iterative learning process that is used to teach a whole range of subject matter. In the context of ESD, a sustainability-related issue may be identified and students asked to investigate this to generate a body of knowledge. They can then develop a vision of alternative actions and potential solutions to the problem, which they use to devise a plan of action. The action may then be carried out, followed by a period of reflection and evaluation. This process promotes both the conceptual and practical aspects of sustainability literacy.
Fieldwork and outdoor learning	Research has shown that fieldwork is an example of experiential pedagogy that can influence students' emotions (Sivek, 2002) and help develop the critical thinking skills so essential to understanding the complexity of sustainability (Jones, 2003; Scott and Gough, 2003). Fieldwork for sustainability is often based on issues in the local community and environs, linking theory to real-world examples (Hope, 2009). There is also evidence that outdoor experience is an important precursor to understanding sustainability (Palmer and Suggate, 1996) and promotes learning by encouraging active learning (Hope, 2009).
Modelling good practice	Learning also taking place implicitly through the hidden curriculum. The research captured how many educators sought to reduce paper use and turned off lights out at the end of sessions as a means of teaching learners the importance of action-taking.

***Table 1** Research into commonly adopted ESD pedagogics in higher education – adapted from Cotton and Winter (2010)* (Tilbury, 2011, p. 26).

2 Pilot Study: Conceptual Framework

This section introduces the aims and setting of the pilot study, reveals the problems and challenges identified from the pilot study and clarifies its implications on developing the conceptual framework for this study.

2.1 Introduction of the Pilot Study

This pilot study was conduct in one TVET institution in Hong Kong. It aims to understand how students and teachers respond to a green enrichment module - **Green Knowledge and Practice** involved in this study, including teachers' pedagogical practice, students' participation and the challenges faced by both teachers and students in teaching and learning this module.

This pilot study employed in-class observation and on-site conversation as research methods. The researcher has conducted 4 in-class observations in two different classes, which have covered 3 different topics within the module, including

- Green office/workplace
- Climate change and carbon footprint
- Sustainable development and corporate social responsibility

The researcher also conduct 4 on-site conversations focused on teaching reflections with two teachers after every in-class observation, and 1 formal conversation with team leader to know about the module setting and discuss the observation feedback.

2.2 Identified problems and challenges in teaching this green module

A number of challenges and problems regarding teaching and learning this module have been identified and they are discussed below.

First, the lecture-based and content-centered pedagogical approach, which organized the lessons into one-way knowledge delivery and ignored students' prior leaning experience and their learning needs, could no stimulate students' learning motivation and provide the opportunities for them to explore the real-world sustainability issues. In addition, the learning content that arranged based on fixed teaching and learning package, which is less locally relevant and hardly relevant to different students' learning or working experiences, cannot support students to make the connection between learning and practice as well as knowledge acquisition and knowledge transformation.

Second, most of the teachers who deliver this module are primarily responsible for teaching other subjects such as surveying, and not specialized in or familiar with the generic green knowledge and practice as well as sustainability issues which are complex and need to be understood and considered in an interdisciplinary context. In addition, most of students did not have any training or learning experiences related to sustainability issues as well. Thus, it posed a serious challenge for teachers to facilitate the development of students' understanding of the sustainability issues and support students to explore the potential ways to address these sustainability problems at the workplace.

Third, although the assessment scheme has included both continuous assessment and end-of-module assessment, some of the assessment formats such as knowledge-based exams may not be so effective in evaluating students' sustainability competences and the intended learning outcomes. These assessment formats would hardly drive students' learning initiatives and facilitate students to explore the real-world problems and make a change. The mini-project as end-of-module assessment does not provide students an opportunity to explore the real-world sustainability problem since the guidance, supervisions and learning resources provided for students are not sufficient. However, these identified challenges are not only faced by the TVET institution in Hong Kong, it seems to be the common issues in sustainability education. For instance, Remington-Doucette et al., (2013) identified the challenge for implementing the sustainability-related introductory course in a university as

> *"students' lack of basic knowledge, skills, and understanding of sustainability concepts and methodologies and a dearth of instructor capacity for coordination, supervision, and facilitation of a large number of real-world projects each semester."* (p. 411)

Similarly, it indicates that students are lack of learning ability, prior learning experience and knowledge related to sustainability, and the instructors' capacity for supporting students' project learning and fulfilling students' learning need in sustainability are insufficient as well.

2.3 The Implications on developing the conceptual framework

This section focuses on the implications of the pilot study on the development of the conceptual framework for this study and it includes aspects of teaching content, pedagogy, assessment and intend learning outcomes.

Teaching Content

1) Campus-based curriculum. There is a need to make full use of the campus recourses to develop curriculum. The workplaces on campus could be also considered as real-world learning recourses.
2) To use students' prior learning experience to generate the learning content. This may turn a perceived disadvantage of "students' background are varied" to an advantage that use different backgrounds as a source for cross-disciplinary learning.
3) The learning content could be reoriented to be more locally relevant through utilizing of local cases to organize learning activities and lead students' discussion.

Pedagogy

1) Constructing learning environments based on learner-centred approach, and employing the pedagogical strategies, which could encourage students' participation and stimulate their learning interest, such as
- Participatory/collaborative learning
- Problem-based learning
- E-learning technologies

2) Making the connection between this generic module and students' major subject by individualized learning or inquiry-based learning within a small group.
3) Integrating characteristics of Education for Sustainable Development (ESD) into the pedagogical practice.
4) Creating more learning resources for students by cooperating with industry's experts and inviting them to share some experience / ideas about sustainability: how do they deal with environmental issues on response to green economy restructuring.

Assessment

1) Employing formulate assessment to encourage more class participation. Part of the assessment could be allocated as students' presentation on a specific topic and group discussion on sustainability.
2) Learning portfolio could be used for reporting the project progress at least once a week, so that more guidance could be given based on students' reflection and the quality of the project learning could be maintained.
3) Evaluation of students' learning outcomes should base on a more systemic competence framework, which clearly specified green knowledge, attitude and skills that students expected to have.
In summary, this pilot study helped to identify the problems and challenges in implementing green generic modules and formulate an approach towards developing an ESD pedagogical model to facilitate the effective implementation.

3 Preliminary ESD pedagogical model: Problem-oriented and Project-based Learning

This section clarifies the components of the Problem-oriented and Project- organized pedagogical model (POPOL) and illustrates the pedagogies strategies and learning activates within POPOL's four learning phases.

3.1 Problem-Oriented and Project-Organized Learning Model (POPOL)

The preliminary ESD pedagogical model – **Problem-oriented and Project-organized Learning (POPOL)** (Figure 1, see below) was developed based on the findings and reflections from the pilot study and the literature review.
The literature review has revealed the significance of learning through real-world problem solving and solution generating for developing students' sustainability competences. The identified ESD pedagogical models also have a common focus on examining the ways to include real world leaning opportunities and implementing ESD through real world problem solving. However, the pilot study conducted in a TVET institution in Hong Kong indicates that it would be unrealistic to provide students with real world learning opportunities in this green enrichment module.

Thus, this POPOL model was developed to address the gap between approaches suggested in literature and practical situation of the TVET institution, which intend to create real-world learning opportunities through bringing the real-world sustainability problems into classroom and facilitating students to connect the identified sustainability issues with their previous and current learning and working experiences. It places more focus on learning through real-world problem solving instead of learning in the real-world setting. In this way, classroom learning will act as a bridge to connect real-world sustainability problems with students' real-world learning and working experiences based on their individual and industrial context, and to transfer the process of knowledge acquisition to knowledge application for problem-solving inside and outside classroom.

The POPOL model emphasizes three major points:

(1) It integrates the pedagogical approach of **problem-oriented** learning (POL) and **project-organized** learning (PjOL). POL places emphasis on learning through identifying, formulating and exploring the sustainability problems. Here "problem-oriented" refers to designing and organizing the learning contents and activities based on specific sustainability problems, and using problems to drive students' learning motivation, while PjOL focus on organizing learning through group projects that focus on proposing solution options for or even solving the real-world sustainability problems. It is a learning process that takes place among the elements of personal learning, collaboration and problem solving.

(2) It includes the real-world learning opportunities into students' learning through four progressive processes (adapted from Brundiers et al., 2010). The processes of "Bringing the world in" and "Stimulating the world" mainly aim to prepare students with necessary knowledge and skills to further explore the real-world problems, while the processes of "Visiting the world " and "Engaging with the world" principally aim to encourage students to apply the knowledge into their learning and working context. However, the learning processes for "knowledge acquisition" and "knowledge application" are not fixed. For instance, visiting and engaging with the world can also facilitate the knowledge acquisition. Here place emphasis on knowledge acquisition through "Bringing the world in" and "Simulating the world" is to emphasize the importance of preparing students with knowledge and skills to further engage in real-world problem solving. More specific learning objectives and learning activities for each learning phases are illustrated in table 2.

(3) It emphasizes that the design of pedagogical strategies, learning contents and learning activities should facilitate students to understand the local issues in a global context and recognize that the solutions to local problems can have global consequences, vice versa. In addition, it should also encourage students to connect their individual and industrial experiences with the identified issues in order to simulate the engagement in real-world contexts.

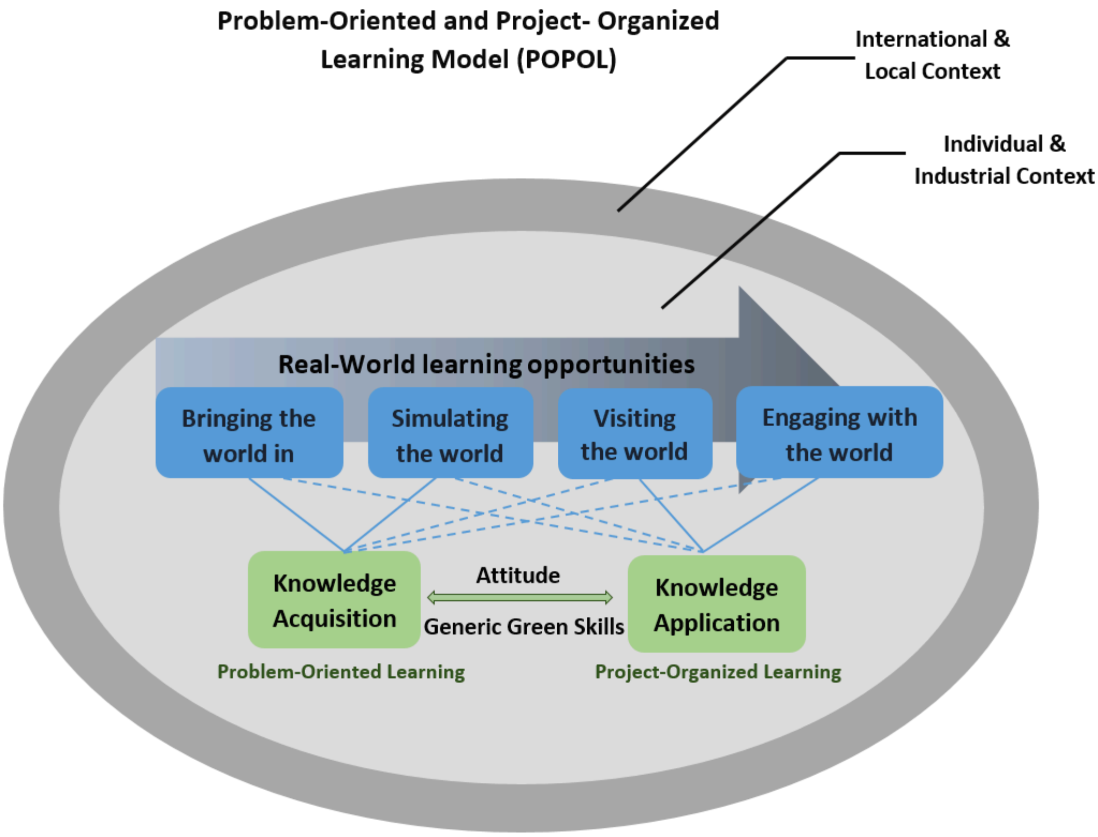

Figure 1 Problem-oriented and Project-organized Learning Model **(POPOL)**
Source: Author

3.2 Suggested pedagogical strategies and learning activities based on POPOL model

The pedagogical strategies and activities in table 2 are suggested based on the review on ESD pedagogical strategies and the consideration of the learning setting within the involved TVET institution. Each pedagogical strategy suggested in the framework is based on specific learning objectives and their corresponding green skills within different learning phases. Both pedagogical strategies and learning activities can include additional forms of learning, which provide ESD learning opportunities for students and encourage them to engage in the exploration of sustainable development issues.

Learning Phases	Learning Objectives	Generic Green skills	Pedagogical Strategies(e.g.)	Learning Activities(e.g.)
Bringing the world in	• Identify and formulate the real-world sustainability problems; • Understand the key concepts and current situation related to the identified issues.	Cognitive competence	• Lecturing • Case study (problem-oriented)	Draw a concept map; Analyze the critical incidents within international and local context (e.g. compare different solutions).
Simulating the world	• experience the dynamics of communication; • Learn how to deal with various perspectives and conflict resolution.	Cognitive & interpersonal skills	• Stimulus activities/ discussion • Debates • Peer-review activities	Reflection on related videos, photos and documents
Visiting the world	• Connect students' learning and working experience to the identified issues.	Intrapersonal & interpersonal competencies	• Group discussion • Case study (Industrial context)	Poster presentation (present a real-world sustainability problem explored in the group project);
Engaging with the world	• Propose potential solutions and strategies for the identified issues	Cognitive, Technological & interpersonal skills	• Group project	Interview Questionnaire Field- observation

Table 2 Pedagogical Design framework for classroom practice
Source: Author

Conclusions

In summary, the study has reviewed the relevant key concepts and identified the gap oESD pedagogical approaches and strategies, which identify the lack of ESD pedagogical study in TVET context and the gap between approaches suggested in literature and practical situation in universities and institutions. Moreover, it illustrated the findings of a pilot study and revealed its implication on intervention planning, which together with literature review to facilitate the formulation of a theoretical framework for a preliminary ESD pedagogical model.

This study has a potential to contribute to both the theoretical and practical developments related to the use of ESD pedagogy for developing generic green skills in the TVET. It enriches an understanding of ESD pedagogy and its role in facilitating effective implementation of green modules and developing students' generic green skills. It also responds to the research gaps by providing empirical evidences on employing ESD pedagogy in TVET context. However, the data collected for this pilot study may be not rich enough since the pilot study was conducted only in one institution. In addition, based on the findings, a subsequent study will focus on exploring the ways on how the developed ESD pedagogical model can contribute to greening the curriculum within TVET institutions.

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Requirements for Multi-Method Approaches to Sustainability Assessment – A Theoretical and Empirical Study

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Abstract
One key element of furthering sustainable development in politics, society, economy and technology is analyzing and assessing the sustainability of products, processes, strategies and organizations. For this, there are numerous approaches to sustainability assessment. Due to the multi-perspective, multi-dimensional and complex nature of sustainability issues, an increasing number of approaches aims at integrated, holistic assessments, e.g. regarding multiple sustainability dimensions, life cycle phases, input types or stakeholder-perspectives. In this context, a growing focus lies on multi-method or combined approaches. Due to this variety and rapid developments, as of yet, there is no systematic overview of requirements for multi-method approaches to sustainability assessment. This impedes structured comparisons and well-founded selection of suitable approaches for respective assessment situations, as suitability and fulfillment level of requirements are neither comprehensible nor verifiable. To fill this gap, the objective of the proposed work is to contribute to developing a set of requirements for multi-method sustainability assessment approaches. The development is based on a theoretical and an empirical pillar: first, existing approaches and requirements-sets are analyzed based on relevant literature to deduce an initial requirements-selection. Second, a first round of semi-structured, qualitative expert interviews is conducted and evaluated to begin gathering and systemizing insights from sustainability assessment experts from science and practice. Both, the theoretical and empirical indications are then consolidated to develop a preliminary requirements-set. The results contribute to developing a holistic systematization and comparison framework and, thus, facilitate well-founded approach selection. This fosters sustainable development by providing valid and credible assessment results.

Keywords: Sustainability Assessment; Methodological Requirements; Expert Interviews; Multi-Method Approaches

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Introduction

In the light of today's major societal issues, such as climate change, scarce resources, environmental pollution, social inequalities and increasing environmental awareness sustainable development and sustainability are widely acknowledged as international, political and societal goals. This is underlined by the seventeen Sustainable Development Goals (SDGs), published and implemented by the United Nations (UN) in 2016, which now represent the core of numerous national sustainability strategies (United Nations, 2016). Also, businesses and other organizations increasingly include the SDGs into their strategies. Sustainable development and sustainability seem to have surpassed the stage of being idealists' goals. However, there is a broad consensus, that our society is only at the beginning of tackling the great issues mentioned above. Thus, claims for (more) sustainable practices and principles can be observed in diverse fields, such as politics, society, economy and technology (Azevedo, Godina, & Matias, 2017; Ghadimi, Yusof, Saman, & Asadi, 2013; Ness, Urbel-Piirsalu, Anderberg, & Olsson, 2007; Singh, Murty, Gupta, & Dikshit, 2009).

To foster sustainable development, which is considered as the pathway to sustainability (Reid, 2013), stakeholders, and especially decision makers, need contextual information on the progress towards sustainability – i.e. the status quo, target values as well as short- and long-term actions to promote sustainable development (Bebbington, Brown, & Frame, 2007). For this, there are numerous approaches to measure, analyze and assess sustainability (Bebbington et al., 2007; Ghadimi et al., 2013; Ness et al., 2007). Examples for approaches, used in the context of sustainability assessment are Life Cycle Assessments (LCA), Multi-Criteria-Decision-Analysis (MCDA) approaches or System Dynamics Modelling (SDM), to name but a few (Bitter, Janssen, Vossen, & Hees, 2018). Within this multitude of approaches, a growing focus lies on multi-method approaches, which aim at accounting for the complexity of sustainability issues – i.e. multi-dimensionality, life cycle and supply chain perspectives, multi-stakeholder contexts, subjectivity etc. (Bond, Morrison-Saunders, & Pope, 2012; Hacking & Guthrie, 2008; Hák, Moldan, & Dahl, 2012; Waas et al., 2014).

An increasing number of publications on the subject of sustainability assessments cover the state of the art of assessment approaches including detailed descriptions of approaches, qualitative comparisons based on potentials and limits of approaches as well as guidelines for selection and comparison (cf. section References). However, there is a lack of publications on systematization and comparison frameworks and comprehensive criteria-sets for approach characterization (Bond et al., 2012; Ghadimi et al., 2013). Such frameworks and respective criteria-sets, based on a solid theoretical foundation, could, however, aid a structured selection and comparison of suitable approaches for different assessment contexts. That way, potential assessment errors, inconclusive results or vulnerability towards criticism and doubts regarding the assessments' credibility, are reduced (Gasparatos & Scolobig, 2012). Such effects can be results of choosing unsuitable assessment approaches and have the potential to decelerate sustainable development. To close the identified gap, the authors' overarching research goal is to develop a comprehensive systematization and comparison framework for multi-method sustainability assessment approaches. In the in the early stages of framework development, two central questions arise, that need to be answered to move forward:

1) How can multi-method sustainability assessment approaches be described, characterised and thus, systemized and compared?
2) How should current, potential and future multi-method sustainability assessment approaches be designed from users' perspectives?

A comprehensive set of systematization and comparison criteria, as proposed by Bitter et al. (2018) provides an answer to the first question. It can be used to describe and characterize assessment approaches and thus, provide potential users of the developed framework with necessary background information and a structured overview of approaches' characteristics. However, the current version of the criteria-set merely allows for a qualitative description of assessment approaches. To facilitate a more structured systematization and reliable comparisons, comprehensible scales for the criteria are needed (Bitter et al., 2018). Building on the first one, the second question aims at finding target values for the criteria as well as insights regarding relevance and importance of each criterion. These two aspects contribute to scale development and building a basis for more structured approach selection processes for users of the framework. Target values as well as weights of criteria can be deduced from requirements, which express desires and/or needs of users of sustainability assessment approaches. In other words: requirements represent *how assessment approaches should be designed from users' perspectives*.

Focusing on the second research question, the goal of this paper is to contribute to developing a requirements-set for multi-method sustainability assessment approaches. To reach this goal, theoretical insights from an analysis of literature on sustainability assessment as well as requirements for approaches in this field, are combined with first empirical indications from interviews with experts in the field of sustainability assessment (cf. Figure 1).

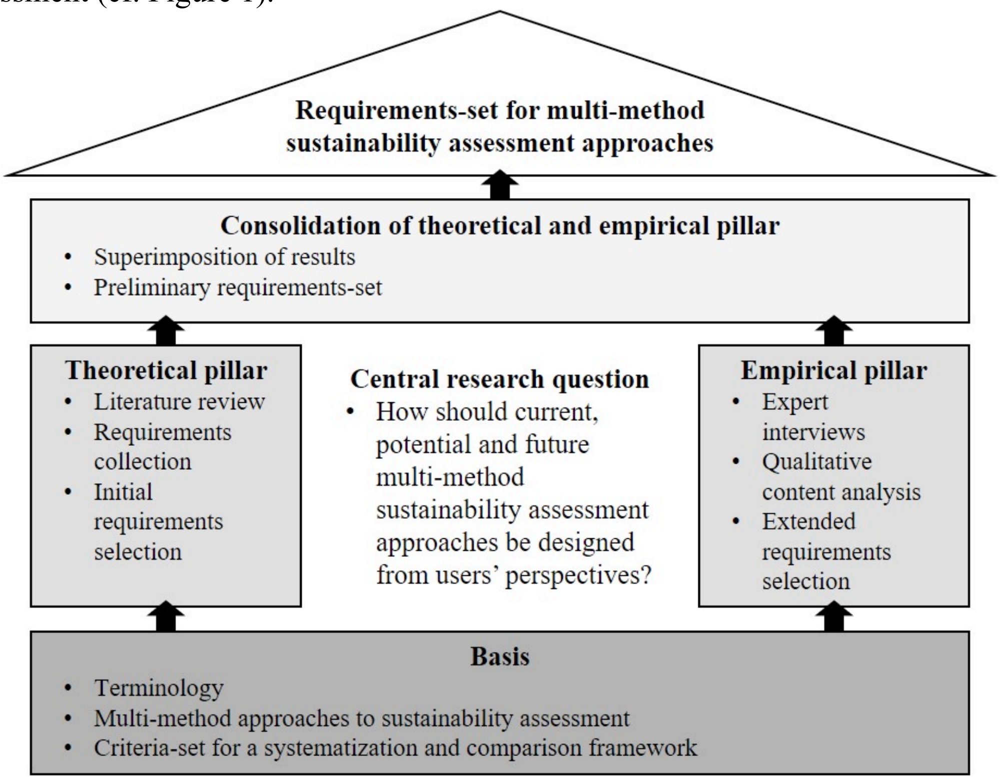

Figure 1: Research approach of this work

The remaining sections of this work are structured as follows. In the next section, the terminology used in this study is defined and described. Subsequently, an overview of multi-method approaches to sustainability assessment is given and the criteria-set, proposed by Bitter et al. (2018), is presented to describe, characterise, systemize and compare approaches. Following, the methodology of literature analysis (i.e. theoretical pillar) and expert interviews (i.e. empirical pillar) is described. Then, insights from literature analysis, including a first requirements selection are presented before results from first expert interviews are presented and linked to the theoretical findings. Finally, conclusions are drawn and an outlook is given in the last section.

Terminology – Sustainability, Sustainability Assessment, Methodological Perspectives

Despite an increasing focus on *sustainable development*, *sustainability* and respective principles, as of yet, there is no undisputed definition of the terms. However, building on the UN's definition – *"sustainable development [...] meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Brundtland et al., 1987) – a *"commonly accepted notion of sustainability describes a holistic concept, that tries to reconcile human activities with the carrying capacity and exhaustibility of the natural environment and human needs – today and in the future"* (Bitter et al., 2018). The widely acknowledged sustainability dimensions *ecology*, *economy* and *social issues* reflect this notion, which is also adopted in the present work (Gibson, 2006; Kleine & von Hauff, 2009). Similarly, to date, there is no agreement on one single definition of the term *sustainability assessment* (Bond et al., 2012). Also, there are parallel terms, such as *sustainability appraisal*, *integrated assessment* or *sustainability impact assessment*, which all lead in the same direction and are – for the purpose of this study – viewed as synonyms (Pope, Bond, Hugé, & Morrison-Saunders, 2017). What all of these terms have in common is that they see the assessment as *"[...] a process that leads decision making towards sustainability"* (Bond & Morrison-Saunders, 2011; Bond et al., 2012; Hacking & Guthrie, 2008). This generic definition, however, leaves a lot of room for interpretation, which leads to a broad variety of approaches (Bond et al., 2012).

In the context of sustainability assessment there is a wide range of terms being used by different authors (Sala, Farioli, & Zamagni, 2013). This does not only apply for sustainability assessment itself, but also for different levels of methodological perspectives on the assessment and its elements. Terms being used in this context are, for example, *framework*, *concept*, *approach*, *methodology*, *method*, *model*, *tool*, *index*, *indicator* and more (Bitter et al., 2018; Sala et al., 2013). While it is not the aim of this work to define all these terms conclusively, for a better understanding, the ones used in this work are described and put into context in the following Figure 2.

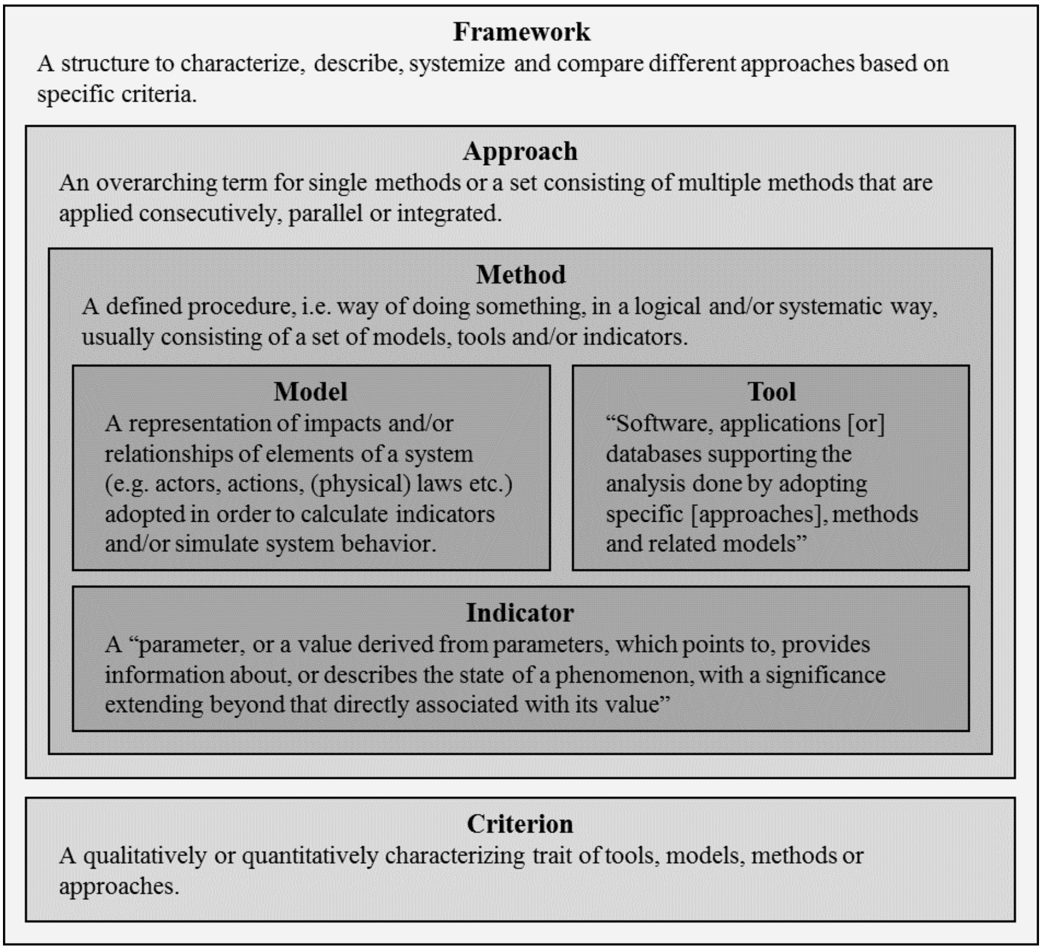

Figure 2: Terminology adopted in this work and hierarchical context (derived from: OECD, 2003; Sala et al., 2013)

Multi-Method Approaches to Sustainability Assessment

Sustainability assessment approaches are generally applied in various fields, such as the assessment of products, processes, businesses and organizations or politics. Their main objective is to measure, analyze and assess the (progress towards) sustainability of the respective assessment object and thus provide decision making support (Azevedo et al., 2017; Ghadimi et al., 2013; Ness et al., 2007; Singh et al., 2009). In recent years, multi-method or combined approaches have increasingly been put into focus in the context of sustainability assessment. This relates to two main factors. First, sustainability and sustainable development are complex constructs and an increasing number of assessment approaches is tailored to account for this fact (Sala, Ciuffo, & Nijkamp, 2015). In this context, complexity refers to multidimensionality – i.e. ecology, economy, social issues – a life cycle or supply chain perspective, a multitude of stakeholders and actors affected by and/or involved in the respective issue, dynamic properties and an interrelatedness of factors, to name but a few. Single approaches are seldomly equipped to account for the full complexity of sustainability issues, thus multiple methods are combined (Sala et al., 2015). Second, sustainability assessments can generally encompass different assessment process stages, such as *stakeholder and indicator selection*, *data collection and pre-processing*, *assessment logic*, *representation of results*, and *derivation of measures*. Approaches consider either single stages, multiple stages or fully integrate all stages (Bitter et al., 2018; Hacking & Guthrie, 2008). Different assessment methods are suitable for different process stages, thus, commonly, to include multiple stages or reach an integrated assessment, multiple methods are combined (Liu, 2014; Wang, Jing, Zhang, & Zhao, 2009). It is neither feasible nor expedient to present and discuss all existing approaches to sustainability assessment within this work. Examples are *Life Cycle Sustainability Assessment* (LCSA), a combination of *LCSA and SDM* or the *Fuzzy Logic Approach to Sustainability Assessment Based on the Integrative Sustainability Triangle* (Fuzzy-IST). An extensive review of multi-method approaches to sustainability can be found in Bitter et al. (2018). Further descriptions of mentioned and unmentioned approaches used in the context of sustainability assessment can be found in the relevant literature (cf. section References). To facilitate description, characterization and thus, systematization and comparison of the enormous variety of multi-method sustainability assessment approaches, the overarching research goal is the development of a systematization and comparison framework based on a comprehensive criteria-set. This is presented in the following section.

Criteria-Set for a Systematization and Comparison Framework

Based on a review of multi-method approaches for sustainability assessment as well as existing frameworks and categorizations Bitter et al. (2018) propose a set of 20 criteria to characterize sustainability assessment approaches. Table 1 contains the criteria and short descriptions. An exemplary characterization of the Fuzzy-IST using the criteria-set can be found in Bitter et al. (2018).

Criterion	Description
Category of approach	E.g. LC, MCDA or other approaches as well as further subcategories (e.g. outranking, distance-to-target etc.)
Focused sustainability dimension	Ecology, economy and social issues or approaches, considering intersections of two or all three dimensions
Focused LC stages and/or parts of the supply chain	Which parts of the LC and/or supply chain are included, up to holistic approaches, integrating the entire LC/supply chain
Included assessment-process elements	The focus on different process stages
Type of input data	E.g. quantitative or qualitative data, numerical or linguistic inputs
Scope of application or generalization level	Targeted range of applications for different objects of investigation
Level of integration	Assessment of different aspects (e.g. sustainability dimensions/LC phases) integrated or side-by-side
Standardization and transparency	Level of comprehensibility and repeatability of assessment processes and results
Data sources	Primary or secondary data, expert knowledge, simulations, analogies or others
Weighting and/or normalization of indicators or criteria	If and which type of weighting and/or normalization is incorporated
Output type	absolute or relative measure(s), single or multiple numerical output(s), graphical representation
Dynamism	Assessment based on a static state ("*snapshot*") or on a dynamic model, that considers interdependencies
Temporal characteristics	Retrospective/descriptive or prospective/predictive evaluation

Table 1: Systematization and comparison criteria, as proposed by Bitter et al. (2018)

Criterion	Description
Treatment of uncertainties	If uncertainties are ignored, deliberately incorporated, minimized etc.
Ease of use or applicability	The cost (time, money, effort) for conducting the assessment and accessibility of assessment procedures and principles
Participation and democracy	How stakeholders and/or experts are involved in the assessment
Accuracy or level of detail	Precision and reliability of the assessment from rough estimate or general tendency to exact output
Substitutability of indicators/ dimensions or handling of trade-offs	Degree to which indicators or sustainability dimensions balance out negative/positive effects of other indicators/dimensions
User(s) and/or target group(s)	E.g. decision makers, analysts, private individuals
Number of combined methods	-

Table 1 (cont.): Systematization and comparison criteria, as proposed by Bitter et al. (2018)

The criteria-set, as a first step towards framework development, enables systematization and comparison of existing and potential, new method combinations for sustainability assessment. That way, a structured selection process is facilitated, that goes beyond generic rules or guidelines. The current version of the criteria-set, however, has two major shortcomings. First, it currently merely allows for a qualitative description of assessment approaches (Bitter et al., 2018). Consistent scales for each criterion would facilitate a more structured and somewhat standardized classification of assessment approaches within the framework and thus, comparison between approaches. Such scales could be, for example, binary, e.g. *yes/no*, based on linguistic sets, e.g. *bad – medium – good*, or a numerical interval, e.g. *[0,1]* as degree of fulfillment. To develop consistent scales target values for criteria are needed, that can be used as lower and upper thresholds. Second, the set of 20 criteria might be comprehensive, as it represents various characteristics of assessment approaches, but the current version does not provide any insights about possibly differing relevance and/or weights of different criteria. In this context, it needs to be validated, if all of the 20 criteria are equally relevant or necessary for a sufficient systematization and comparison of assessment approaches. To tackle these shortcomings and drive the framework development forward, in this work, requirements for multi-method sustainability assessment approaches are collected. The methodology applied for building a requirements-set is further elaborated in the following section.

Methodology – Theoretical and Empirical Pillars

To include theoretical insights from the magnitude of existing literature on sustainability assessment approaches as well as practitioners' expertise and standpoints, the present work is based on a two-pillar approach: theoretical and empirical. To build the first one, three sub-steps are followed:

1) Literature review of scientific sources related to multi-method sustainability assessment approaches and existing requirements-sets
2) Collection of requirements for multi-method sustainability assessment approaches, mentioned and/or described in the literature reviewed
3) Clustering of synonymous and/or related requirements in form of an initial requirements selection

For the second pillar, semi-structured, guideline-based expert interviews (Bogner, Littig, & Menz, 2009) are conducted and evaluated using qualitative content analysis, based on Mayring (2014). A semi-structured approach using an interview guideline allows the interviewer to adapt to the course of the conversation and, if necessary, to deviate from the interventions included in the guideline. Thus, experts' knowledge and opinions can be freely explored while at the same time, the guideline provides an easy to follow structure for the interviewer (Bogner et al., 2009). The interview guideline consists of ten open interventions, clustered in five phases (cf. Table 2). It is subject to continuous adaption based on insights from the conducted interviews. The focused topics, however, remain constant through all interviews. The target group of the interviews are experts in the field of sustainability assessment. This includes interview partners from the scientific world, economic enterprises, politics and administration as well as non-governmental organizations.

Phase / Topic	**No.**	**Intervention**
Initial impulse	Q1	Please describe to me your understanding of the term "sustainability assessment".
Sustainability assessment practices	Q2	There are numerous approaches or methods for sustainability assessment. Which one(s) do you use or have used before?
	Q3	In which contexts do you use or have you used these methods?
	Q4	What goal(s) are or were you aiming at by applying these methods?
	Q4a	*Which other approaches to sustainability assessment do you know? (optional)*
Requirements for sustainability assessment approaches	Q5	When selecting an approach for a specific assessment context, what are your selection criteria?
	Q6	Considering these criteria, what are general requirements for approaches to sustainability assessment?
	Q7	When thinking about the assessment contexts you are familiar with, as discussed before, what are specific requirements for sustainability assessment approaches regarding these contexts?
Fairness	Q8	I have one last question for you. One requirement for approaches to sustainability assessment might be to provide a "fair" assessment. In your opinion: what would be an appropriate definition or description of "fair" in this context?
Additional aspects	*Q9*	*Do you have any additional comments or aspects, that you would like to talk about?*

Table 2: Interview guideline (phases / topics and interventions)

The expert interviews are audio-recorded and evaluated based on Mayring (2014). The goal of the evaluation is to reconstruct the interviewees' ideas, expertise and opinions from interview data, based on a theoretical framework, guided by rules, systematic and thus, comprehensible for third parties. A qualitative content analysis consists of five steps:

(1) transcription of audio-recording, (2) redaction of statements based on initial questions, (3) organizing statements according to topics, (4) explication, i.e. interpretation and explanation of interviewees' ideas, expertise and opinions and (5) structuring of contents and concepts (Mayring, 2014). Based on this evaluation, in the context of this work, requirements for sustainability assessment approaches are collected. Similar to the first pillar, the collected requirements from different interviewees are clustered according to synonymous and/or related aspects. At the time of publication, N = 4 interviews have been conducted and evaluated. Further interviews are scheduled and thus, the results of the empirical part of this work should be understood as preliminary.

As a third step, the results of both, the theoretical and the empirical pillar are consolidated. For this, the collected requirements-sets are compared and synonymous and/or related aspects are clustered. Thus, by superimposing both sets, a first requirements-set is developed. In the following sections, insights from both pillars and from a preliminary consolidation of the resulting requirements-collections are presented.

Theoretical Insights – Initial Requirements Selection

The literature reviewed can be divided into two main categories (C1 and C2). On the one hand, sources containing *implicit* insights about requirements for sustainability assessment approaches (C1). In many cases, these works are concerned with various approaches, including those regarding the state-of-the-art or specific groups of approaches, e.g. LC approaches, MCDA approaches, approaches for assessments on product or company level etc. On the other hand, sources providing *explicit* statements or collections of requirements – i.e. descriptions how approaches to sustainability assessment should be designed (C2). Sources, that explicitly cover requirements for sustainability assessment approaches, on the one hand, confirm the initial findings from the first category. On the other hand, new aspects can be added to the overview. In some works, terms like *criteria* (Baumgartner, 2004; Thabrew, Wiek, & Ries, 2009) or *principles* (Pintér, Hardi, Martinuzzi, & Hall, 2012; Wang et al., 2009) are used instead of *requirements* (Bitter et al., 2016; Liu, 2014; Sala et al., 2015, 2013). However, all of these terms refer to statements or claims, how sustainability assessment approaches should be designed and are thus, understood as synonyms for the purpose of this work.

In the following Table 3, the initial requirements-selection from literature analysis, consisting of 25 requirements (R1–R25), is summarized. The table contains a short description of each requirement and sources of both categories. The requirements are sorted according to the number of sources.

No.	Requirement	Sources
R1	Include a **holistic perspective** of the sustainability dimensions	[8]–[10], [12], [14]–[20]
R2	Include **strategic perspective** to **contribute** positively to sustainable development	[5], [9], [14]–[20]
R3	**Systemically** reflect relevant characteristics and impacts	[1], [11], [16], [18], [20], [21]
R4	Foster **comparability** and **objectivity** of inputs, processes and results	[3], [11], [13], [16], [18], [21]
R5	Allow for **stakeholder** participation and **transdisciplinary** processes	[6], [16], [18]–[20]
R6	Provide a **life cycle perspective**	[7], [8], [10], [12], [20]
R7	Focus on **integrated assessments**	[8], [12], [14], [17], [19]
R8	Represent the individual and overall **performance** of indicators	[6], [15], [16], [18], [19]
R9	Assure **consistency** of inputs, assumptions, system boundaries, results	[1], [4], [7], [21]
R10	Clear, understandable **communication** and/or **visualization** of results	[1], [12], [16], [20]
R11	Include only **measurable**, boundary-oriented indicators	[15], [16], [19], [21]

Table 3: Initial requirements-selection and sources

No.	Requirement	Sources
R12	Assure **reliability** and **validity** of inputs, processes and results	[11], [13], [15]
R13	Process **uncertainty**, **subjectivity** and **incomplete** data-sets	[12], [18], [19]
R14	Focus on **transparency** of inputs, assumptions, overall approach, results	[16], [19], [20]
R15	Processing of **quantitative AND qualitative** data	[2], [12]
R16	Recognize and **avoid trade-offs**	[7], [10]
R17	Provide a **practicable**, i.e. usable, feasible and efficient approach	[11], [12]
R18	Assure an **adequate** temporal and/or geographical **scope** of assessment	[15], [16]
R19	Facilitate a **continuous**, **flexible** assessment process	[16], [20]
R20	Provide **decision making support**	[1], [15]
R21	Foster **scalability** and **transferability** of results	[18], [19]
R22	Deal with **cross-sectoral** issues	[20]
R23	Allow for the assessment of different scenarios	[20]
R24	Avoid **independencies** and/or account for **interdependencies**	[21]
R25	Promote (social) **learning** and feedback	[18]

Legend:
C1 sources: [1] = (Abu-Taha, 2011), [2] = (Andriantiatsaholiniaina, Kouikoglou, & Phillis, 2004), [3] = (Cherchye, Knox Lovell, Moesen, & Van Puyenbroeck, 2007), [4] = (Gamboa & Munda, 2007), [5] = (Gibson, 2006), [6] = (Hermans, Erickson, Noordewier, Sheldon, & Kline, 2007), [7] = (Kloepffer, 2008), [8] = (Møller, Slentø, & Frederiksen, 2014), [9] = (Pope et al., 2017), [10] = (Valdivia et al., 2011);

C2 sources: [11] = (Baumgartner, 2004), [12] = (Bitter et al., 2016), [13] = (Chatterji & Levine, 2006), [14] = (Hacking & Guthrie, 2008), [15] = (Liu, 2014), [16] = (Pintér et al., 2012), [17] = (Pope, Annandale, & Morrison-Saunders, 2004), [18] = (Sala et al., 2013), [19] = (Sala et al., 2015), [20] = (Thabrew et al., 2009), [21] = (Wang et al., 2009);

Table 3 (cont.): Initial requirements-selection and sources

Preliminary Expert Interview Results

At the time of publication N = 4 expert interviews have been conducted. Three of the experts interviewed are from the scientific world (E1–E3) and one is from an economic enterprise (E4). In the following, the interviewees' responses are summarized and clustered according to the topics and questions, as presented in Table 2. Similarities and differences between the expert interviews are highlighted.

- **Q1 – Understanding of "sustainability assessment"**: The scientists' understanding of sustainability assessment incorporate the three sustainability dimensions ecology, economy and social issues, with a greater focus on ecology, representing the concept of *strong sustainability* (Morrison-Saunders, Pope, & Bond, 2015). For them, these dimensions are represented by indicators and target values to measure the status quo or progress towards sustainability. The expert from industry (E4), however, makes no differentiation between sustainability assessment and other business-related assessments, as sustainability is seen as integral part of the enterprise's strategy.

- **Q2 – Applied approaches to sustainability assessment**: The experts use various approaches to sustainability assessment. Some of them are mentioned multiple times, some just once. E1–E3 use *LC-based approaches* with comprehensive or reduced indicator sets and varying foci (e.g. carbon footprint, climate aspects, resources). Their main focus lies on the concept of *material input per unit of service* (Liedtke et al., 2014). E2 and E3 also use *Hot-Spot Analysis*, a qualitative approach based on literature analysis and expert interviews (Liedtke, Baedeker, Kolberg, & Lettenmeier, 2010). Other approaches that are mentioned by E2 are *resource efficiency potential analysis* (REPA) and *risk analysis*, which are both mainly quantitative approaches. Also, *network* and *media analyses* are used by E3 to qualitatively identify relevant stakeholders for sustainability issues as well as analyzing sustainability-related discourses or popular perceptions. Furthermore, E3 names *nutritional footprinting* as an approach to combine quantitative, resource-focused sustainability assessments with the dimension of health (Lukas, Rohn, Lettenmeier, Liedtke, & Wiesen, 2016). E4 stresses, that there is no differentiation between sustainability assessments and other assessments in the company. An approach, that has been used in the past is *stakeholder surveys*, in the sense of *materiality analyses*, to investigate the relevance of different topics and estimate the company's performance regarding relevant topics. Another approach is to qualitatively and quantitatively *estimate* possible ecological and social *impacts* of the company's actions as a decision basis for the members of the board of directors. This approach was phased out and replaced by a streamlined document-based tool accompanied by coordination processes prior to strategic decisions. E4 points out, that the approaches being used are not standardized, but rather tailored to the company's needs and structures.
- **Q3 – Context of sustainability assessments**: The contexts, in which the interviewees apply the abovementioned approaches to sustainability assessment, are broad. E1 argues to look at "everything" and names examples, such as *products*, *materials*, *supply chains* and *national economies*. E2 focusses on *comparing* assessments of *products* and production *processes* but also mentions assessments of *households* and individual *lifestyles* as well as bio-energy, biomass, agriculture and related *impacts*. E3 is mainly concerned with *products*, *services*, *processes* and *households* but also deals with *systemic* assessments, for example related to *supply chains* or *city quarters*. This expert also differentiates assessment contexts into research projects and sustainability consulting for third parties, such as companies or government. E4's single focus lies on assessments prior to strategic decisions, which can be regarding, for example, investments, products, business relationships or communication.
- **Q4 – Goals of sustainability assessments**: Assessment goals that are mentioned multiple times are to *optimize* products, processes or entire companies (E1–E4), to *prepare decisions* on different levels, e.g. households, companies or national economies (E1, E3, E4) and to *compare* different alternatives, e.g. products, strategies or lifestyles (E1–E3). E1 also mentions, in the past, one goal was to *develop a database* resource analyses but this goal was abandoned, as extensive databases already exist. E2 names the *reduction of impacts*, e.g. of resource consumption, as an overarching goal. E3's prioritized goal is to *foster a sustainable transformation* of society and contribute to providing insights on *"real" sustainability* values of practices,

products and services. For E4, a main goal is to *embed sustainability concepts* (e.g. the Triple-Bottom-Line) into the company's "DNA".

- **Q5 – Selection criteria for sustainability assessment approaches**: All experts argue, that there are *no specified, objective selection criteria* in their assessment practice. On the one hand, this relates to a specific set of approaches or methods that are commonly applied in the experts' organizations (see above). On the other hand, the experts point out that method selection always depends on the assessment goal and expected and/or desired results. E1, for instance, mentions "authenticity" as a reason why always the same (resource-focused) approaches are chosen, which are then tailored to the specific assessment context. For E2, it is clear to first define the assessment goal und respective questions and then to select an appropriate approach. E3 states, that methods are chosen according to clients' wishes or requirements and/or according to individual expertise or capacities. Many clients, however, prefer quantitative assessments, as data often is available and results are easy to communicate. E3 also remarks, that commonly it is not questioned whether a method or an approach is suitable and/or sufficient and, for example, should be combined with another method or approach. For E4, there is no selection process at all, as assessment approaches are always pre-defined.
- **Q6/7 – General and specific requirements for sustainability assessment approaches**: The experts do not differentiate between general and specific requirements or the specific requirements they mention overlap with the general ones. In the following Table 4, requirements are listed and attributed to the different experts.

Requirement	**Expert(s)**
Transparency and comprehensibility regarding the assessment process, assumptions, goals and conclusions	E2–E4
Accompany numerical values with context-sensitive verbal explanations / interpretations	E1, E2
Do not overestimate assessment as the "absolute measure"	E1, E2
Provide a long-term perspective	E1, E3
Display a realistic image of the relevant system, e.g. regarding relevant stakeholders, balance of power or influences	E3, E4
Reliability of the assessment and its results and Resilience against external changes and/or changing assumptions	E1
Focus on process-oriented indicators to account for changing conditions	E1
Assure relevance of assessment object	E1
Do not suggest false accuracy / be aware of uncertainties	E1
Chose appropriate scales for assessment object and focused system level	E1
Assure comparability of the assessment and its results	E2
Provide a decision basis	E2

Table 4: Resulting requirements from questions Q6 and Q7

- **Q8 – Fairness**: With regards to a possible requirement of a *fair* assessment, the experts provide their own definitions or descriptions of *fairness* in the context of sustainability assessment. E1 points out that fairness mainly relates to embedding an assessment into the specific assessment context. The general *conditions*, *system boundaries* and the *position* in the life cycle and/or supply chain need to be considered. Comparisons under different conditions or assumptions, e.g. of different branches, regions, parts of the supply chain, are seen as *unfair*. The expert also remarks that it is crucial to assess the *impact* of single system elements on the entire system, e.g. a product's life cycle or supply chain. E2 names several aspects of a fair assessment. First, for comparisons, the same *assessment basis* needs to be used. Second, with regards to lifestyles and consumption, *resources* need to be *distributed equally*. Third, the overall goals of the assessment need to be in the interest of *public justice* or *equity*. Fourth, a fair assessment should be transparent. The expert also remarks, that assessment results should always be seen as a decision basis, but not as an *absolute truth*. E3, however, connects fairness with targeting the SDGs and their objectives by including *target values* or a target corridor into the assessment. The expert argues, that current standards or recommendations should always be combined and (re-)evaluated with sustainability goals. Finally, E4 suggests that fairness connects to *transparency* regarding communication and goals of the assessment. For business activities, a certain *continuity* and *reliability*, e.g. with regards to the understanding of sustainability, is also relevant for fairness. At last, the expert states that an aspect of fairness is a timely *feedback* from third parties, if sustainability goals are not met, to effectively correct negative impacts.

- **Q9 – Additional remarks**: All experts have additional remarks, that are not directly related to any of the questions above. E1 and E4 point out, that there is a significant *gap* between sustainability assessment practices in the scientific and economic world. The approaches developed by scientists are often too complex and detail-oriented for an implementation in companies. Thus, *streamlined approaches* are needed (E1). E4, as a representative of the economic world, suggests two possible ways to close that gap: either scientists develop (streamlined) approaches which are then used by companies or scientists conduct assessments themselves. According to E4, the results of both ways will most likely be very different. The experts from science, E1–E3, also point out, that assessment results can be easily *influenced* and, thus, *manipulated* by choosing different sustainability assessment approaches. Finally, E4 remarks, that sustainability should not have a *special status*, especially for companies, but be seen as an integral part of the strategy. By avoiding a *parallel world* for sustainability issues, the concept itself might be more successful.

In the third step of this work's research approach, the preliminary results of the expert interviews are linked to the literature analysis. A first consolidation of both pillars is presented in the following section.

Preliminary Consolidation of the Theoretical and Empirical Pillar

The first round of expert interviews provides further insights on requirements for multi-method sustainability assessment approaches. By superimposing their results with the initial requirements selection (cf. Table), several of these requirements are confirmed by the experts, others are added to the list. The results of the superimposition are presented in the following Table 5.

No.	Requirement	Confirmed / Added
R1	Include a **holistic perspective** of the sustainability dimensions	**Confirmed** (E1–E4; Q1)
R2	Include a **strategic perspective** to **contribute** positively to sustainable development	**Confirmed** (E1–E4; Q4, Q6/7)
R3	**Systemically** reflect relevant characteristics and impacts	**Confirmed** (E1, E3, E4; Q6/7, Q8)
R4	Foster **comparability** and **objectivity** of inputs, processes and results	**Confirmed** (E2; Q6/7)
R6	Provide a **life cycle perspective**	**Confirmed** (E1–E3; Q2)

Table 5: Superimposed requirements-set from the theoretical and empirical pillar

No.	Requirement	Confirmed / Added
R11	Include only **measurable**, boundary-oriented indicators	**Confirmed** (E3; Q8)
R12	Assure **reliability** and **validity** of inputs, processes and results	**Confirmed** (E1, Q6/7)
R13	Process **uncertainty**, **subjectivity** and **incomplete** data-sets	**Confirmed** (E1, Q6/7)
R14	Focus on **transparency** of inputs, assumptions, overall approach and results	**Confirmed** (E2–E4, Q6/7, Q8)
R15	Processing of **quantitative AND qualitative** data	**Confirmed** (E2–E4, Q2)
R17	Provide a **practicable**, i.e. usable, feasible and efficient approach	**Confirmed** (E1, E4; Q9)
R18	Assure an **adequate** temporal and/or geographical **scope** of the assessment	**Confirmed** (E1; Q6/7)
R19	Facilitate a **continuous**, **flexible** assessment process	**Confirmed** (E1; Q6/7)
R20	Provide **decision making support**	**Confirmed** (E1–E4; Q4, Q6/7)
R25	Promote (social) **learning** and feedback	**Confirmed** (E4; Q8)
RA1	Accompany numerical values with context-sensitive verbal **explanations** / **interpretations**	**Added** (E1, E2; Q6/7)
RA2	Do not **overestimate** assessment as the “absolute measure”	**Added** (E1, E2; Q6/7)
RA3	Assure **relevance** of assessment object	**Added** (E1; Q6/7)
RA4	Provide **new insights** regarding the assessment object and create **expert knowledge**	**Added** (E3; Q6/7)
RA5	Promote **ambitious**, but **achievable goals**	**Added** (E4; Q6/7)

Table 5 (cont.): Superimposed requirements-set from the theoretical and empirical pillar

From the previous table, it can be seen that 15 of the 25 initial requirements are confirmed by a small number of experts (N = 4). Another five requirements are added from the interviews. All experts point out that, in their understanding, sustainability is represented by the three dimensions ecology, economy and social issues. Thus, they focus on a *holistic perspective of sustainability* in the context of assessments. This directly relates to R1, which is repeatedly named as a requirement in sustainability assessment literature (cf. Table). This underlines the importance of avoiding one-sided assessments to account for sustainability’s complexity. Furthermore, all experts aim at including a *strategic perspective* into sustainability assessments to contribute positively to sustainable development (R2). Again, being a requirement frequently mentioned in the literature, this stresses the importance of having specific, sustainability-driven goals when conducting an assessment, e.g. improving products or processes. This also links to the unanimously named requirement of providing *decision making support* (R20), which directly reflects sustainability assessments definition as *"[...] a process that leads decision making towards sustainability"* (Bond & Morrison-Saunders, 2011; Bond et al., 2012; Hacking & Guthrie, 2008). Other requirements that are, in each case, stated by three experts, are to *systemically* reflect relevant characteristics and impacts (R3), to provide a *life cycle perspective* (R6), to focus on *transparency* of inputs, assumptions, overall approach and results (R14) and to process *quantitative and qualitative* data (R15), underlining the importance of these requirements.

Conclusion

The results of this work provide a first overview of requirements for multi-method approaches to sustainability assessment, thus, approaching an answer to the question *"How should current, potential and future multi-method sustainability assessment approaches be designed from users' perspectives?"* (cf. section Introduction). The results indicate, that the prevalent requirements are, on the one hand, driven by characteristics of sustainability and, on the other hand, by general desires towards assessment approaches. The first category relates to aspects, such as sustainability as a *holistic* concept, a *strategic* goal, a complex *system* or a *life cycle*-wide issue. The second category includes a perception of assessment approaches fostering *decision support*, being *transparent* or processing multiple types of *inputs*. This points to the conclusion, that multi-method sustainability assessment approaches should be designed to account for the complexities of sustainability while adhering to general standards for assessment approach.

However, due to the small sample size (N = 4), the results of this study cannot be regarded as conclusive. They rather provide valuable indications, as discussed above, on which further research can be based on. Because of this, concrete target values and weights of the criteria and thus, comprehensive scales, could not yet be deduced within this study. However, to finalize the development of a comprehensive requirements-set for multi-method sustainability assessment approaches, more interviews will be conducted. Thus, initial indications from this work shall be validated or contradicted and additional insights about sustainability assessment practices, goals and approach selection processes shall be gained. A next step in framework-development is to relate the systematization and comparison criteria with the requirements-set to deduce target-values, and, thus, scales for the criteria as well as insights regarding relevance and importance of each criterion. That way, the framework being developed, gains in applicability and validity. Thus, method selection and combination for sustainability assessment are structured and facilitated. Finally, this fosters context-adequate, more reliable and valid assessment results and more sustainable decisions.

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