Sustainable design of the GUST small wind turbine

Karol Zawadzki¹, Anna Baszczyńska, Małgorzata Stepień, Angela Fliszewska, Szymon Molenda and Marcin Pisarski

Institute of Turbomachinery, Lodz University of Technology, 90 - 924 Lodz, 219/223 Wolczanska Street, Poland

¹E-mail: karol.zawadzki@edu.p.lodz.pl

Abstract. One of the increasingly important criteria, when constructing a Small Wind Turbine (SWT), is its sustainable design. It means constructing the SWT in such a way that it can provide a cheap, easy and safe access to clean energy at a specific location for predicted number of consumers. This paper highlights three issues. First, benefits from the application of the rapid prototyping technology are discussed. 3D printers can be used as a durable and relatively cheap means of SWT components production. Also, the possibility of using recycled plastic for 3D-printed components is of big importance. Secondly, the modular construction of the small wind turbine is outlined. This facilitates the product versatility, proneness to adjustments and ease of maintenance. Last but not least, the production costs for individual units as well as multi-unit production are reviewed to show the financial benefits of SWTs and the payback of such investments over the years. The article concludes with a set of recommendations for wind turbine design, conformal with the suggestions of the UN Sustainability Report and Sustainable Development Goal 7.1. The utilization of described concepts is demonstrated basing on the GUST 1.6 m diameter horizontal axis SWT.

1. Introduction

Securing access to energy is one of the contemporary challenges standing in the way of stable growth of developing countries. Beginning with fulfilment of basic human needs, through any type of technological advancements improving the quality of life – the access to energy is undeniably a vital aspect. Still, the most commonly used resources for energy generation base on fossil fuels – depletable, environment-degrading and increasingly expensive. It is estimated that 2.8 billion people use, as cooking fuels, traditional solid energy sources like wood or coal, while 1.2 billion still have no access to electricity at all [1]. However, basing on the “Renewables 2019” report [2], it is indicated that at the end of 2018 more than 26% of global electricity production was generated from renewable energy, mostly solar and wind power. A report created by the Global Tracking Framework, a multi-agency study led by the World Bank and the International Energy Agency, indicates the course to achieve universal energy access, double the use of renewable energy and improve energy efficiency [1]. These targets strongly resonate with the Sustainable Development Goals (SDGs) introduced by the United Nations [3], particularly SDG 7.1: to ensure (by 2030) universal access to affordable, reliable, and modern energy services. Rural areas of Sub-Saharan Africa are particularly affected by the lack of easily available sources of clean energy. Therefore, to meet SDG 7.1, special efforts should be made to provide access to the renewable energy sources (RES) in the mentioned regions [3]. In this context, one of the most promising types of energy sources are small wind turbines (SWTs) [4]. However, in order to construct the SWT that meets the Sustainable Development Goals, numerous specific
conditions (like local weather, profitability in the long-term use, financial resources and knowledge) should be considered at the design stage.

1.1. Sustainability aspects of the SWT design
To provide sustainability of power generating systems it is necessary to consider a variety of environmental and economic conditions. A wide range of SWT types enables to match an appropriate device for diverse, specific needs, regardless of climatic zone. Developing countries and remote village areas, which are still often deprived of electricity sources, require simple, easily maintainable and relatively cheap solutions. There are various methods that can be utilized to increase sustainability and significantly reduce costs of SWT installations, especially in Sub-Saharan Africa regions.

1.1.1. 3D-print. Nowadays, the 3D-printing technology is eagerly applied in multiple branches of science and industry. This type of additive manufacturing is suitable not only for rapid prototyping process [5], but also becomes increasingly important in the small-batch manufacturing [6]. Objects produced with this method can be characterized by small part size and complex shape. The specification of 3D-printing technology allows to produce highly customized elements in low volumes and with high repeatability. The variety of available manufacturing materials includes polymers, resins or even super alloys, such as nickel-based chromium alloys [6]. What is more, 3D-printing is considered as a manufacturing process with a high potential for production resource and energy reduction, with a possibility of decreasing the production-related CO₂ emission [7, 8]. Regarding the available methods, one of the most popular 3D-printing techniques is the Fused Deposition Modelling (FDM) [9]. It uses a thermoplastic material in form of a filament. It is melted and applied layer by layer to build a complete model. Thermoplastics are materials that can be recycled, which is a valuable feature from the point of view of economics and ecology [10]. This makes unwanted or wasted products possible to be reused, according to the circular economy idea aiming “to close the loop of product lifecycles through greater recycling and reuse, and bring benefits for both the environment and the economy” [11].

1.1.2. Modular assembly. Efficient arrangement of the components and ease of assembly of complex mechanisms, such as SWT, is best achieved with the modular design of their subsystems. This term refers to the collection of distinct blocks that combined, build a complete system. Every separate block or sub-assembly has a different function and can be freely modified without the influence on the whole structure [12]. Introducing the modularity into the design process provides numerous advantages in terms of sustainability of the final product. The device can be easily customized, the production process is economic and the lead-time is reduced. Moreover, the product can be easily maintained and repaired [13]. The modular construction allows to customize the device for multiple sustainable purposes along its lifecycle. The concept of modularity in engineering pioneered in the 1960s [14]. Modular product design (MDP) and its benefits for product sustainability have been widely studied for several years and many design methods have significantly evolved. Traditional methods of modular product design include matrix-based and decoupling algorithms [15], cluster-identification algorithms for product redesign [16] or fishbone diagrams which identify relationships between particular modules [17]. Modularization is considered to be an effective method to compromise between environmental consciousness and providing a wide assortment of products [13].

1.1.3. Profitability estimation. Determining the costs (and, consequently, the payback time) of an SWT is an important aspect from the point of view of a single consumer. It allows to assess the overall profitability of the investment. For instance, the approximate payback time of a 50-kW turbine operating at an average wind speed of 6.6 m/s is less than 10 years (taking into account the price of energy 0.25 EUR / kWh) [18]. Considering the SWTs, the time required to fully recover costs of their construction can take from 6, to even 30 years [19]. For instance, according to the American consumers’ claims, the SWT payback time can be estimated to 15 years, as for example in the case of
the 400-Watt rooftop HAWT located in Rockford (northern Illinois, USA) [20]. In addition to that, SWTs also present numerous non-financial benefits. They have a high potential for the sustainable development, mainly considering distributed generation and low-cost technologies [4]. According to [4], the investment costs in case of SWTs are remarkably smaller than for big wind turbines. What is more, SWTs also contribute to decreasing the dependence of countries on foreign energy supply and simultaneously develop many benefits for the domestic economy [21].

2. Overview of the GUST SWT
The Team GUST (Generative Urban Small Turbine) designed and constructed a small wind turbine for the purpose of energy generation and use by individual consumers (prosumers) living at locations in Sub-Saharan Africa: Potiskum (Nigeria), Calvinia (South Africa), Atsbi (Ethiopia), and the Kesses Region (Kenya). Four versions of the SWT were investigated in terms of their efficiency:
- “3 blades 1.00” (3-bladed version with the average chord 0.08 m, shown in figure 1(left).
- “4 blades 1.00” (4-bladed version with the average chord equal to 0.08 m, figure 1(right).
- “3 blades 1.33” (3-bladed version with the average chord increased by 33% and equal to 0.1067 m).
- “4 blades 1.33” (4-bladed version with the average chord increased by 33% and equal to 0.1067 m).

Figure 1. 3- and 4-bladed variants of the GUST SWT.

All aforementioned versions of the rotor have fixed-pitch blades, whose geometry is based on the NREL S826 aerofoil. The swept area of the rotor is equal to 2 m² and the rated rotational speed is equal to 335 RPM. The GUST SWT can operate in the wind speed range from 3 m/s to 15 m/s, with the rated wind speed equal to 5 m/s. A synchronous, permanent-magnet, off-the-shelf generator is used. Considering the outcomes from the wind tunnel tests at the International Small Wind Turbine Contest, the nominal power of the turbine is equal to around 750 W [22, 23].

In order to make the prototype affordable and cost-effective for the application in the Sub-Saharan region, special emphasis on sustainability criteria was placed. The modular assembly of mechanical parts and use of simple manufacturing techniques play an important role in the design process. The Team took the profitability of the constructed SWT into consideration as well. The cost estimation and payback time for four variants of the wind turbine was calculated. Basing on the obtained results, the version most attractive for consumers from the financial point of view was chosen (see Section 3.3).

3. Sustainable design of the GUST SWT
This chapter will discuss the most important aspects of the sustainable design of the GUST small wind turbine.

3.1. 3D-print
Considering all benefits of using the 3D-printing technology, the importance of biodegradability and recyclability of numerous filament types is essential from the point of view of sustainability. This
section focuses on the importance of 3D-printed components regarding the sustainable design of the GUST wind turbine.

Acrylonitrile Butadiene Styrene (ABS) is a type of thermoplastic material that was used in manufacturing components for GUST SWT. The granules of virgin ABS material are used to make the filament. With its use, the 3D-printed models can be manufactured. To recycle the waste material, the mechanical shredder brakes the model to obtain again the small granules of ABS. The re-use of the filament, however, changes its mechanical and thermal properties. Although the recycled material shows decreased tensile strength after the first cycle, the further deterioration of mechanical properties does not appear with consecutive recycle series. What is more, combining the recycled granules with the virgin material gives a possibility to create a blend, which has good mechanical properties and meets the criteria of sustainability [24].

Due to the benefits of additive manufacturing, all GUST wind turbine components indicated in figure 2 are created by means of 3D-printing technology separately and are recyclable due to the use of ABS filament.

![Figure 2. 3D-printed elements (marked blue) of the GUST SWT.](image)

The recyclability and biodegradability are, however, not the only necessary criteria to be met. All 3D-printed parts should be resistant to stresses and weather conditions (especially temperature and rainfall) that may appear during the outdoors operation at a particular location. The statistics regarding the temperature and humidity in two locations typical for the Sub-Saharan Africa (Potiskum and Atsbi) are presented in table 1.

| Parameter               | Potiskum [25] | Atsbi [26] |
|-------------------------|---------------|------------|
| Average daily temperature, °C | 35            | 17         |
| Annual rainfall, mm     | 713           | 778        |

ABS is a material, that is impact-resistant and can withstand high temperatures (up to around 100°C). The “glass transition”, which is the moment of liquefaction for this plastic is achieved at the temperature around 100°C [27]. However, the ABS material can soak with water if exposed to moisture or heavy rain conditions for a long time. To prevent this and decrease the negative impact of humidity, the appropriate postprocessing – like the application of the epoxy glue and wax – can be applied. Also such measures as the infill level not less than 40% and wall thickness not less than 3 shell layers increase noticeably the water resistance of the 3D-printed elements [28].

Still, the 3D-printed parts are relatively easy to manufacture, comparing to another manufacturing methods (CNC machining or injection moulding). In all, the use of filament-made parts in the GUST small wind turbine design meets the following sustainability criteria:
• low costs and simplicity in design,
• eco-friendliness (recyclability and biodegradability),
• resistance to weather conditions (for selected filaments),
• possibility to manufacture almost everywhere (3D printers are usually easy to transport due to reduced dimensions).

One should consider also drawbacks of the additive manufacturing. The process is relatively sensitive to printing conditions and settings (temperature, extrusion velocity, etc.). If it ends up with poor accuracy of the 3D-printed parts, it may e.g. provoke problems with the assembly of SWT components. Also, the long printing time can be a noticeable issue [29].

3.2. Modular assembly

The GUST wind turbine is designed in a way, that permits to construct and improve every block separately. This approach provides the possibility of cooperation of numerous design teams, responsible for different modules. The construction of SWT can be divided into the following principle modules (see figure 3 left):
• yawing system,
• rotor,
• generator,
• electronic system.

The cooperation of all wind turbine modules is presented in the flow chart (figure 3 right).

![Figure 3. Sub-systems in the GUST SWT (left) and the interdependence of its modules (right).](image)

3.2.1. Yawing system. The yawing system is composed of a turntable and a tail. The purpose of implementation of this module is to face the wind turbine towards the oncoming wind. It is especially significant in geographical regions, where the wind direction is unstable and often varies. Considering for instance the location of Potiskum, main directions of the wind are north and south, however east and west air currents can also transport an important amount of wind kinetic energy [23].

3.2.2. Rotor. The rotor module is responsible for the conversion of the wind energy into torque, transported further to the generator. The module consists of a previously mentioned set of blades, a dome and a spinner. These parts are directly connected to the shaft, which transports the torque to the generator. The number of blades can be easily changed (e.g. three-bladed rotor can be traded for a four-bladed one) without significant interference with other sub-systems. Also some extra features such as blades with winglets [30] or a diffuser [31] could be employed, if necessary (e.g. for particular environmental conditions).
3.2.3. Generator and electronic system. The electronic system is based on the worldwide available components which are easily accessible. This decreases price of the modules and their complexity, so that only the defective part is replaced in case of a failure. Another advantage is the compact dimensions of the modular electronic system. Printed circuit boards (PCBs) are designed to be easily made in electronic-circuit manufacturing companies. The system can operate for 5 years with full load, according to the estimations based on thermal optimisation of the PCBs and their individual components. The SWT is designed to operate fully autonomously, with low maintenance requirements. Moreover, the turbine is equipped with the RGB diode in the tail in order to warn flying objects/planes and inform about the state of the turbine.

3.3. Cost estimation
The overall cost of GUST SWT construction is estimated at 2052.06€ and 2121.48€ (for a 3-bladed and 4-bladed variant, respectively). The most expensive parts are the electronic components (650.00€) and the generator (564.00€). Among the mechanical parts, the manufacturing of one turbine blade and the nacelle generates the highest expenditure (70.00€ and 87.00€, respectively). Other costs include the elements of the braking system, as well as the hub + rotor system. The breakdown of the manufacturing costs into the main subsystems of a wind turbine is shown in figure 4.

![Figure 4. Sub-systems in the GUST SWT.](image)

To assess the profitability of the GUST wind turbine in the long-term use, the expected Annual Energy Production was calculated (see table 2). Having information about the annual energy gain, the income associated with the use of the SWT was estimated, considering the following assumptions:
- the lifecycle of the GUST wind turbine is estimated to be 20 years [19],
- the cost of energy is for the Sub-Saharan Africa, being equal to 0.18€/kWh (2018) [32].

The energy production, as well as the estimation of the SWT payback period, were calculated for all variants (see Chapter 2). Results are presented in table 2.

| Turbine lifetime (years) | 3 blades 1.00 | 3 blades 1.33 | 4 blades 1.00 | 4 blades 1.33 |
|-------------------------|--------------|--------------|--------------|--------------|
| Investment cost (€)     | 2052.06      | 2121.48      |              |              |
| Cost of 1 kWh (€/kWh)   |              |              |              |              |
| Energy production (1 year, kWh) | 742.90 | 806.25 | 796.15 | 835.17 |
| Energy production (20 years, kWh) | 14858.03 | 16125.07 | 15923.06 | 16703.44 |
| Income (1 year, €)      | 133.72       | 145.13       | 143.31       | 150.33       |
| Income (20 years, €)    | 2467.42      | 2902.51      | 2866.15      | 3006.62      |
| Simple payback (years)  | 15.35        | 14.14        | 14.80        | 14.11        |
| NPV (Net Present Value, €) | 134.49 | 320.95 | 221.81 | 336.65 |
| IRR (Internal Rate of Return) | 2.67% | 3.56% | 3.05% | 3.58% |
The Annual Energy Production is of the highest magnitude for the 4 blades 1.33 version of the GUST SWT and is equal to approximately 835.17 kWh. This yields almost 16125 kWh during turbine lifecycle. Other variants produce similar outcomes. The income after 1 year is of the lowest value for the 3 blades 1.00 version. Basing on the aforementioned outcomes, the average payback time is estimated to approximately 14-15 years for every GUST SWT model. This is a satisfactory result, comparing with existing and commercially available small wind turbines. Considering for instance the Zephyr Airdolphin SWT (3-bladed model with the rotor swept area equal to 2.54 m²), the payback time is equal to 63 years. For another commercial small wind turbine, Whisper 200 (3-bladed rotor with the swept area 5.73 m²), the financial return period is 25 years [19].

Net Present Value (NPV) and Internal Rate of Return (IRR) are the economic indicators presenting profitability of the entire investment in wind energy harvesting system. NPV is the return on investment cost [33], assuming discount rate equal 2% and the operation time 20 years. For all four configurations of the GUST wind turbine, the IRR (which may be understood as an interest rate from the investment [33]) gives values approximating at 3%. This gives positive results and guarantees the profitability of the investment. The NPV value is the lowest for the “3 blades 1.00” variant (134.49€) and the highest for the “4 blades 1.33” version (336.65€). Considering the aforementioned results, the most profitable business option for the consumer is the variant “4 blades 1.33”. It is the most cost-effective and most attractive for the potential customers.

Taking into account the overall price of the GUST SWT, the manufacturing costs may be decreased substantially by the production of a greater number of units. Manufacturing turbine components repeatedly without major modification brings the noticeable decrease of the production process costs. It is possible due to the modular assembly of the GUST wind turbine, which consists of many components manufactured on a large or mass scale. Costs of the manufacturing process of a single model of a wind turbine in series production are estimated using the following formula [18]:

\[ P_n = B_n T f^{\ln n / \ln 2} \]

where: \( P_n \) – costs of the n-th unit; \( B_n \) – costs of the first unit; \( n \) – number of units; \( T_f \) – technology factor.

Technology factor of industrially manufactured products usually varies between 0.80 and 0.96. For example, the factor for the aircrafts industry varies between 0.80 and 0.90. On the other hand, for the wind turbine the best technology factor range varies between 0.90 and 0.95 [18]. The greater the number of mass-produced wind turbines, the lower their unitary cost is. It is showed in figure 5 depending on different values of the technology factor.

![Figure 5. The cost of a single unit of SWT in mass production.](image)
One can observe that, for example, for $T_f = 0.95$ the price of the construction of one SWT produced in 1500 units reaches only the 58% of the total cost of manufacturing of a single wind turbine prototype.

4. Conclusions and comments

The presented article highlights the economical aspects of SWT installations and proposes solutions that visibly increase sustainability of the product. The utilized methods and cautious consideration of specific environmental conditions result in a proposal of a 1.6 m diameter SWT, suitable for multiple locations in Sub-Saharan Africa.

Among all the variants analysed under the described assumptions, the four-bladed turbine with extended chord length (marked as “4 blades 1.33”) appeared to be the most profitable. With its ability to produce over 850 kWh of electrical energy annually, the device would provide a simple investment payback after 14.11 years. The income from a power generation of an individual SWT would be equal to 150.33 € after one year and 3006.62 € after 20 years.

Implemented design methods, such as 3D printing and modular construction, ensure that the installation will be easily maintainable, reducing necessity for highly qualified staff during basic repairs. Separate modules can be effortlessly replaced without a risk of causing whole system failure. The GUST SWT design is, therefore, an example of practical implementation of the SDG 7.1, targeted at the developing countries of Africa.

References

[1] Angelou N et al. 2013 *Global tracking framework (English) Sustainable energy for all* (Washington, D.C. World Bank Group)
[2] REN21 2019 *Renewables 2019 Global Status Report* (Paris: REN21 Secretariat) Available: https://www.ren21.net/reports/global-status-report/
[3] *The Sustainable Development Goals Report 2019* Available: https://unstats.un.org/sdgs/report/2019/The-Sustainable-Development-Goals-Report-2019.pdf
[4] Wen T W, Palanichamy C and Ramasamy G 2018 Small wind turbines as partial solution for energy sustainability of Malaysia *Int. J. of Energy Economics and Policy* 9(2) pp 257–66
[5] Lipian M, Kulak M and Stepien M 2019 Fast track integration of computational methods with experiments in small wind turbine development *Energies* 12(9) 1625
[6] Berman B 2012 3-D printing: The new industrial revolution *Business Horizons* 55(2) pp 155–62
[7] Gebler M, Schoot Uiterkamp A J M and Visser C 2014 A global sustainability perspective on 3D printing technologies *Energy Policy* 74 pp 158–67
[8] Kreiger M and Pearce J M 2013 Environmental life cycle analysis of distributed three-dimensional printing and conventional manufacturing of polymer products *CS Sustainable Chem. Eng.* 1(12) pp 1511–19
[9] Masood S H 2014 Advances in fused deposition modeling *Reference Module in Materials Science and Materials Engineering Comprehensive Materials Processing* 10 pp 69–91
[10] Pakkanen J, Manfredi D, Minetola P and Iuliano L 2017 About the use of recycled or biodegradable filaments for sustainability of 3D printing. In: Campana G, Howlett R, Setchi R, Cimatti B (eds) *Sustainable Design and Manufacturing 2017* pp 776–85 *Smart Innovation, Systems and Technologies* 68 (Springer, Cham)
[11] European Commission 2019 *Closing the loop: Commission delivers on Circular Economy Action Plan Brussels*
[12] Tseng M M, Wang Y and Jiao R J 2018 Modular Design. In: Chatti S, Laperrrière L, Reinhart G, Tolio T *The International Academy for Production (eds) CIRP Encyclopedia of Production Engineering* (Springer, Berlin, Heidelberg)
[13] Bryant C R, Sivaramakrishnan K L, Van Wie M, Stone R B and McAdams D A 2004 A modular design approach to support sustainable design *Proc. of the ASME 2004 Int. Design
Koga T and Aoyama K 2009 Modular design method for sustainable life-cycle of product family considering future market changes Proc. of the ASME 2008 Int. Design Engineering Technical Conf. and Computers and Information in Engineering Conf. 5 (Brooklyn, New York, US) pp 3–10

Kusiak A and Wang J 1993 Efficient organizing of design activities Int. J. of Production Research 31(4) pp 753–69

Newcomb P J, Bras B, Rosen D W 1998 Implications of modularity on product design for the life cycle ASME. J. Mech. Des. September 120(3) pp 483–90

Ishii K J, Juengel C and Eubanks C F 1995 Design for product variety: key to product line structuring

Hau E Wind Turbines Fundamentals, Technologies, Application, Economic

Ugur E, Elma O, Selamogullari U S, Tanrioven M and Uzunoglu M 2013 Financial payback analysis of small wind turbines for a smart home application in Istanbul/Turkey Proc. of Int. Conf. on Renewable Energy Research and Applications (ICRERA) (Madrid) pp 686–9

Lombardo T, Rooftop Wind Turbines: Are They Worthwhile? engineering.com, Available: https://www.engineering.com/3DPrinting/3DPrintingArticles/ArticleID/9556/Rooftop-Wind-Turbines-Are-They-Worthwhile.aspx

Chagas C C M, Pereira M G, Rosa L P, da Silva N F, Freitas M A V and Hunt J D 2020 From Megawatts to Kilowatts: A review of small wind turbine applications lessons from the US to Brazil Sustainability, MDPI 12(7) pp 1–25

Kadrowski D, Kulak M, Lipian M, Stepien M, Baczczynski P, Zawadzki K and Karczewski M 2018 Challenging low Reynolds - SWT blade aerodynamics MATEC Web. Conf. 234 01004

Lipian M, Czapski P and Obidowski D 2020 Fluid–structure interaction numerical analysis of a small, urban wind turbine blade Energies 13(7) 1832

Mohammed M I, Wilson D, Gomez-Kervin E, Tang B and Wang J 2019 Investigation of closed-loop manufacturing with acrylonitrile butadiene styrene over multiple generations using additive manufacturing ACS Sustainable Chem. Eng. 7(16) 13955–69

https://weatherspark.com/y/68821/Average-Weather-in-Potiskum-Nigeria-Year-Round

Jacob M, Lanckriet S, Van Vooren S and Nyssen J Dogu’a Tembien’s Tropical Mountain Climate. Geo-trekking in Ethiopia’s Tropical Mountains (Springer, Cham) pp 45–61

Yazdi M H, Lee-Sullivan P 2009 Determination of dual glass transition temperatures of a PC/ABS blend using two TMA modes J Therm Anal Calorim 96 pp 7–14

3D printing of water proof objects for underwater applications, retrieved from: https://docs.beobachtung3d.com/waterproof-3d-printed-objects-for-underwater-applications.html Accessed on: 20.06.2020

Xinyan D 2017 Application of three-dimensional printing technology in the manufacture of wind turbine generator equipment Chemical Engineering Transactions 62 pp 1153–8

Kulak M, Lipian M and Zawadzki K 2020 Investigation of performance of small wind turbine blades with winglets Int. J. of Numerical Methods for Heat & Fluid Flow, in press

Lipian M, Dobrev I, Karczewski M, Massouh F and Jozwik K 2019 Small wind turbine augmentation: Experimental investigations of shrouded- and twin-rotor wind turbine systems Energy 186 115855

South Africa’s petrol and electricity prices vs the world Retrieved from: https://businessstech.co.za/news/energy/306592/south-africas-petrol-and-electricity-prices-vs-the-world/ Accessed on: 21.06.2020

Asma Arshad 2012 Net Present Value is better than Internal Rate of Return Interdisciplinary J. of Contemporary Research in Business 4(8) pp 211–19